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User's Manual for BRNSIM/BURNSIM: A Burn Hazard Assessment Model

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13. ABSTRACT *(Maximum 200 words)*
BURNSIM is an interactive computer model which runs on DEC minicomputers (PDP 11 and VAX), Macintosh and IBM compatible PCs. The model is based on the work of Moritz and Henriques at Harvard, the Surgery Department at University of Rochester; Alice Stoll at Naval Air Development Center and Knox et al. at the U.S. Army Aeromedical Research Laboratory. Its development has been funded by the U.S. Army, U.S. Air Force, and Dr. Knox. The model predicts time to pain and burn depth when bare skin is exposed to any arbitrary time history of heat flux. It predicts burn depth with reasonable accuracy for pig and human skin. A software module to include clothing between the thermal source and the skin has been developed but not integrated with BURNSIM and has not been validated. By using sensors to measure heat flux behind fabric it has been possible to use BURNSIM to evaluate the insulating effect of clothing. BURNSIM has been used in the last several years to assess the burn hazard associated with rocket plumes in side-by-side ejection seats, shoulder launched weapons, nuclear flash and live fire. This manual provides information on model development, its installation and use on a PC.

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The senior author wishes to express his gratitude to the many colleagues who have contributed to the development of BURNSIM. Drs. Stanley C. Knapp, Thomas L. Wachtel, and Chap McCahan have worked on the project from the beginning in 1970 when we were all stationed at the U.S. Army Aeromedical Research Laboratory. Dr. Knapp had started the project to study postcrash fires with funding from various sources including the U.S. Army Medical Research and Development Command and the USAF Life Support Systems Program Office at Wright-Patterson Air Force Base. Dr. Cal Lum helped during the data collection phase in 1972. Dr. Daniel D. Reneau and his graduate student, Nelson O'Young, contributed the basic section of code to calculate the conductive heat transfer. Randy Nockton and Chet Ellis contributed additional software development including tape reading routines, statistical analysis programs and a database to manage the data. Dr. Charles Yuell, a pathologist at the Rochester School of Medicine, helped clarify the burn depth grading scheme and even found some of the original porcine skin samples from earlier burn studies at Rochester. Mr. Chris Perry and CPT Dena Bonetti have worked with BURNSIM for the past 3 years at the Armstrong Laboratory and have contributed to the current effort supported by the Defense Nuclear Agency. Part of this effort is the PC version of BURNSIM for which CPT Dena Bonetti is largely responsible. Funding for this effort has come from the U.S. Army Medical R&D Command, Defense Nuclear Agency, and the U.S. Air Force without which BURNSIM would not have been developed.

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Background

BRNSIM (or BURNSIM as it is now called) is a computer model which allows the user to convert heat flux incident to bare skin to a predicted burn depth. The requirement for such a model arose when there was a need to quantify the thermal protective properties of new flight suits. Techniques employed in the 1960s and very early 1970s did not predict the full range of burns from no burn to full thickness and failed to take into account both initial conditions of the skin and its adaptive behavior when heated.

Since the late 1960s, the U.S. Army Aeromedical Research Laboratory (USAARL) at Fort Rucker, Alabama, has been involved in quantifying the burn hazard associated with post crash fires and the protective capability of flight clothing[1]. USAARL staff (including the author) conducted a number of field studies using burning helicopters to establish the severity and time course of post crash fires (Knapp and Knox, 1982). They also 1) built and used two fire simulators to study the effect of simulated postcrash fires on pigs as an analog for man (Knox et al., 1978b), 2) placed fabrics between the fire and the pigs to study their protective capability (Knox et al., 1980), 3) assembled a large porcine (pig) burn database using this bioassay method (Knox, 1979a), and 4) developed the model, BRNSIM, to decrease the workload associated with using the bioassay method to assess fabric protective capabilities (Knox, 1979b).

The starting point for building BRNSIM (short for burn simulation) was the work of Alice Stoll who based her model on Moritz and Henriques' damage integral (Henriques, 1947). She had collected data from human volunteers on the time/heat flux relationships resulting in threshold transepidermal necrosis. This burn is represented by minor blister formation. To explain her results she added a consideration of damage occurring during cooling as well as during the heating phase (Figure 1). Stoll chose the constants (Stoll and Greene, 1959) in her model to fit her human data on threshold burns; more severe burns were not at first considered. Later Weaver and Stoll (1969) proposed an extension of Stoll's first model to include more severe burns without experimental basis.

The first model to come out of the USAARL program was that of Art Takata of IITRI (Takata, 1974) who worked for USAARL as a contractor. He started with Stoll's approach and added water boiling as a way of handling blister formation. He then adjusted the constants ($P, \Delta E$) (see equation (7) in Appendix A) to more accurately predict USAARL's data on more severe porcine burns.

[1]The development of this model and the work upon which it is based has been funded by U.S. Army Medical Research & Development Command, Fort Detrick; U.S. Air Force Life Support Systems Program Office and Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio; Defense Nuclear Agency, Washington D.C., and as a personal project by the primary author.

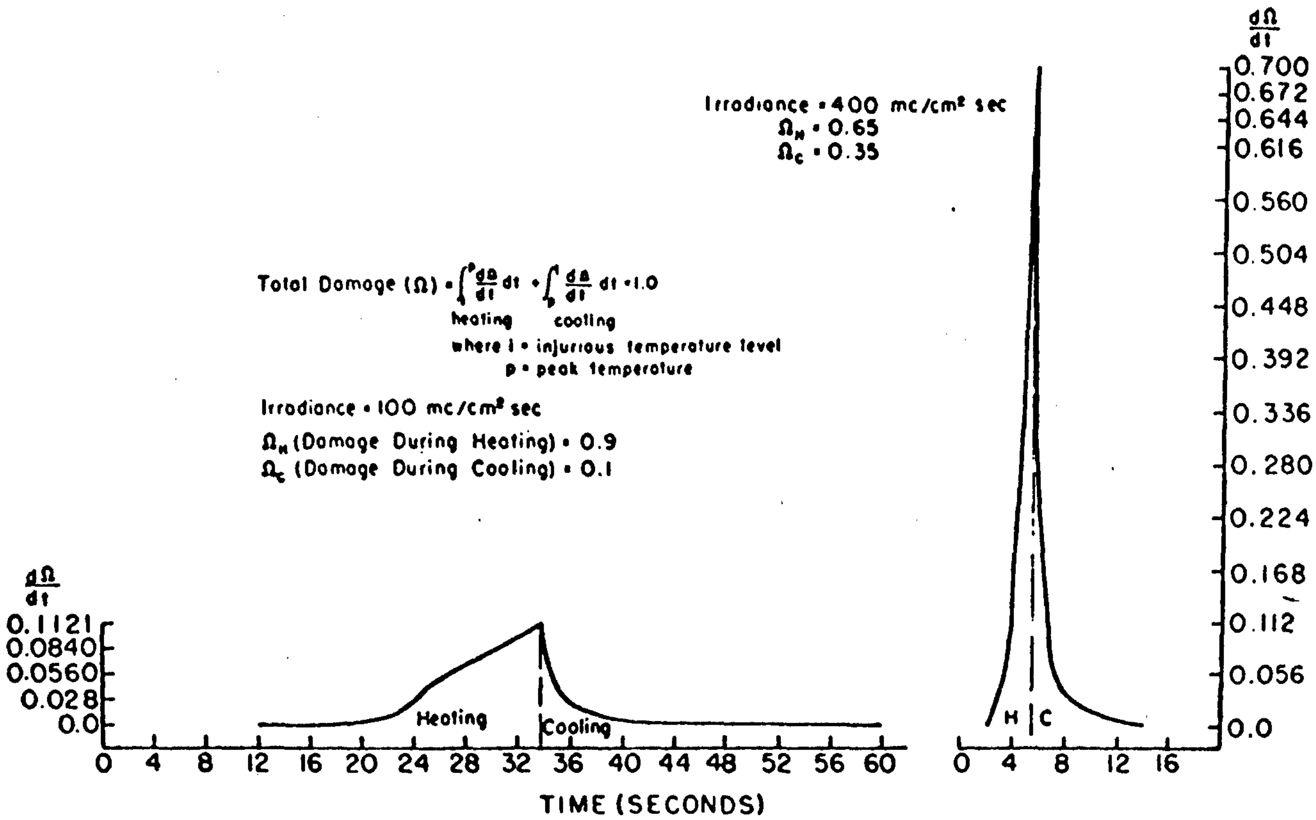

Figure 1. Tissue damage integral indicative of the blister endpoint (Stoll and Chianta, 1971)

The current BURNSIM model builds on these earlier efforts (Henriques, 1947; Weaver and Stoll, 1969; Mehta and Wong, 1973; Morse et al., 1973; and Takata, 1974). It is an interactive model written in both FORTRAN and ZBASIC and runs on PDP 11/40, 11/03, 11/24, VAX 11/780, Macintosh, and IBM compatible PCs.

Model description

BURNSIM considers the skin to be represented as 12 chunks or nodes (See Figure 2). Seven additional nodes can be inserted between the first and second nodes when exposures are mild and burn damage is likely to be shallow (Figure 2). BURNSIM solves the Fourier heat conduction equation to find temperature as a function of time at each node. Then total damage at each node is found by computing the damage integral at each depth. The transition between normal and damaged skin is defined as that depth where the damage integral is equal to one. For a more detailed description of the mathematics of BURNSIM consult Appendix A. BURNSIM source code (FORTRAN version) can be found in Appendix B.

Getting started

BURNSIM has been supplied to you in either source or compiled form. The following instructions are intended to help you use the model. The instructions and comments are based, in part, on feedback received from several users who have attempted to get started without the benefit of this manual. If you have problems using BURNSIM please do not hesitate to call the author at DSN 785-3931 or (513) 255-3931. Future versions of this manual will incorporate your comments and suggestions so that we may continue to improve BURNSIM and to distribute updated versions to the users.

The first step is to load the code for the model into your computer from the medium provided. This step has many versions. Only one example is given because it is assumed that if you are using this model you are sufficiently computer literate to load and compile the source code on your system.

```
PC Example: BURNSIM.FOR, REN12.DAT on floppy disk.
 To run off hard disk:
Set default disk drive to a:
Put diskette in a:
Type  DIR (rtn)
BURNSIM.FOR   REN12.DAT     FLUX.DAT    BURNSIM.EXE
A>CD C:
C>MD C:\BURNSIM
C>CD C:\BURNSIM
C>COPY a:*.* c:
C:\BURNSIM>DIR
BURNSIM.FOR    REN12.DAT    FLUX.DAT    BURNSIM.EXE
C:\BURNSIM>
```

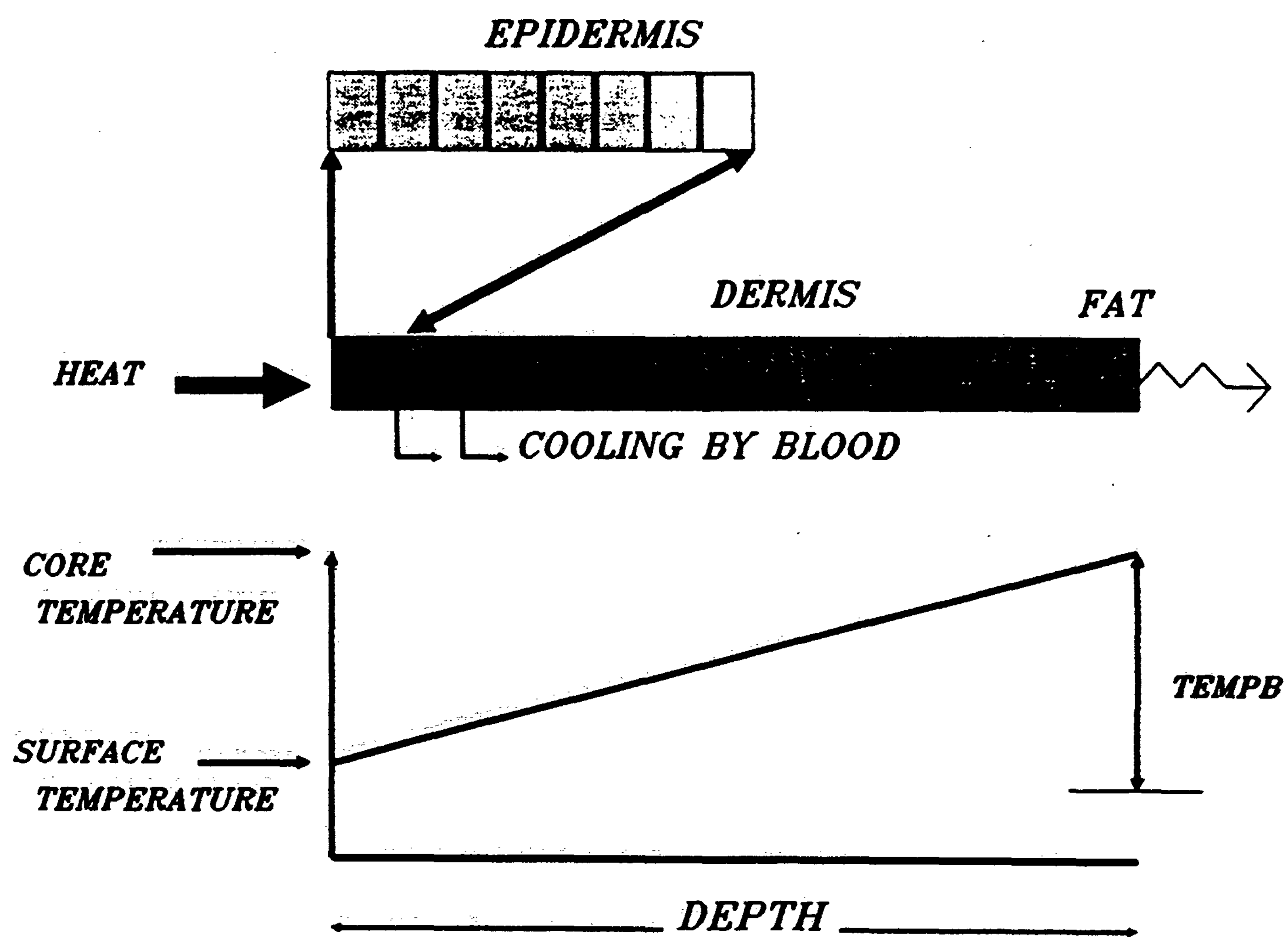

Figure 2. Skin representation

At this point you have made a directory on your hard disk for BURNSIM and copied the files from the floppy to the new directory. The file REN12.DAT contains the initial values of all the variables which are changeable within BURNSIM. Some of these values such as the conductivity and heat capacity for each node can only be changed by creating a new REN12.DAT with an editor or word processing program (see Appendix C for the layout of REN12.DAT). The model expects a flat ASCII file, so if you use a word processor, save the file as an ASCII text file and not a document. Other values such as exposure time (ETIME) can be changed interactively as described below.

To run BURNSIM invoke the command for your system, e.g. RUN BURNSIM or BURNSIM. You will next see the following on the screen:

BURNSIM <CR>

The first screen that you see is shown below:

WELCOME TO BURNSIM. TO BEGIN RUNNING THE PROGRAM, BURNSIM FIRST NEEDS TO KNOW THE NAME OF THE FILE THAT YOU WANT TO STORE THE OUTPUT DATA IN. THIS FILE WILL CONTAIN ALL OF THE INPUT PARAMETERS AS WELL AS THE OUTPUT FOR EACH ITERATION THE MODEL PERFORMS. THIS FILE CAN BE CALLED ANYTHING UP TO EIGHT CHARACTERS LONG.

PLEASE ENTER A NAME FOR THE OUTPUT FILE: **OUTFILE** <CR>

The next screen is shown below:

NEXT BURNSIM WILL SHOW YOU THE PRESENT INPUT PARAMETERS. UNDER THE LIST OF PARAMETERS YOU WILL SEE A QUESTION ASKING IF YOU WISH TO CONTINUE. IF YOU WANT TO EXIT THE PROGRAM AT THAT POINT, TYPE N. OTHERWISE TYPE Y.

TO CONTINUE ON TO THE LIST OF PARAMETERS TYPE A <CR>.

The following screen will appear:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPIO = 32.5000	DENS = 1.00000	Q1 = 3.54000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.5000	ABSORB = .61300	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 3.02000	ITIME = 80.00000	NXTRA = 0
BLOOD = .00100		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

DO YOU WISH TO CONTINUE? TYPE Y OR N Y <CR>

Answer yes (Y) to continue and you will be presented with the following choices:

TYPE THE NUMBER OF THE FUNCTION BELOW THAT YOU WISH TO PERFORM.

CHOOSE A FUNCTION NUMBER:
1 - CHANGE SELECTED INITIAL VALUES
2 - NO CHANGES--CONTINUE RUNNING THE PROGRAM
3 - EXIT

PLEASE ENTER THE FUNCTION NUMBER: 1 <CR>

Choose #1 to change the set up values. This will give you the following screen:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPIO = 32.5000	DENS = 1.00000	Q1 = 3.54000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.5000	ABSORB = .61300	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 3.02000	ITIME = 80.00000	NXTRA = 7
BLOOD = .00100		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

DO YOU WANT TO MAKE ANY CHANGES? Y OR N Y

Answer yes (Y) here to change the input values using the following screen:

PICK A NUMBER

1=TEMPIO	8=ETIME
2=DENS	9=PL1
3=Q1	10=PLN1
4=BL	11=PL2
5=AK	12=PLN2
6=JINC	13=DE1
7=TEMPB	14=DE2

15=ITIME	16=ABSORBTIVITY	
17=BOIL	18=EXTRA NODES	
19=BLOOD	20=APL1	
21=APLN1	22=APL2	
23=APLN2	24=ADE1	25=ADE2

Choose the number representing the parameter you wish to change. The definition of these parameters is in Table I. For example, set up one of Stoll's published cases (Weaver and Stoll, 1969). In this case, the human skin was exposed for 5.6 seconds at 0.4 cal/cm^2-sec. The skin was blackened with India ink to set the absorbtivity at 94 percent. Start by choosing #3 to set the incident flux level, Q1. The model responds with:

ENTER THE FLUX FILE NAME (TYPE A <CR> IF NO FILE
IS TO BE USED): <CR>

Since Stoll's case has a constant flux value, type a ⟨CR⟩ and the following will appear on the screen:

CONSTANT Q-VALUE = 3.5400000 INPUT NEW VALUE: **0.4** <CR>

The old value was 3.54000 and the new value entered was 0.4 cal/cm^2-sec.

****

If you do later simulations where you wish to read in a file of varying flux values instead of using a constant flux value, type the name of the flux file in response to the following statement:

ENTER THE FLUX FILE NAME (TYPE A <CR> IF NO FILE
IS TO BE USED): **FLUX.DAT**

The file **FLUX.DAT** is the example flux file given on the disk. When creating flux files to be read into BURNSIM, remember that the file name can be no more than eight characters in length including the .DAT ending. Also the file must contain only one column of data, the flux data, in units of cal/cm^2-sec. The number of points in the flux file and the sample interval between points must be known, too.

Continue to input responses to the following statements concerning the flux file as they appear on the screen:

ENTER FLUX ID (UP TO 8 CHARACTERS): **IDFLUX** ⟨CR⟩

The FLUX ID can be any combination of 8 characters.

ENTER THE NUMBER OF POINTS IN THE FLUX PROFILE: **100** ⟨CR⟩

The maximum number of points that can be read in is 600.

ENTER THE SAMPLE INTERVAL IN SECONDS: **0.1** ⟨CR⟩

*** Note: When using a flux file for the incident flux, the exposure time (ETIME) variable must be set equal to the number of points in the flux file minus one times the sample interval in seconds. For this example, ETIME = (100 - 1) x (0.1) = 9.9 seconds.

****

The next screen is shown below:

```
                         SKIN DIFFUSION DATA
                         INPUT PARAMETER LIST

TEMPIO =  32.5000      DENS =   1.00000       Q1 =     .40000
BL =    .22000         AK =    .01000         JINC = 12
TEMPB =   4.5000       ABSORB =    .61300     BOIL =  100.15000

PL1 =   1.46000        PLN1 = 147.37000       DE1 =    50000.0
PL2 =   2.24000        PLN2 = 239.47000       DE2 =    80000.0
ETIME =   3.02000      ITIME =  80.00000      NXTRA =  7
BLOOD =    .00100

APL1 =    .78000       APLN1 = 285.52000      ADE1 =    93534.9
APL2 =    .60000       APLN2 = 117.43000      ADE2 =    39109.8

          DO YOU WANT TO MAKE ANY CHANGES? Y OR N Y
```

Answer yes (Y) here to change the next input value using the following screen:

```
PICK A NUMBER

   1=TEMPIO             8=ETIME

   2=DENS               9=PL1
   3=Q1                 10=PLN1

   4=BL                 11=PL2
   5=AK                 12=PLN2

   6=JINC               13=DE1
   7=TEMPB              14=DE2

   15=ITIME             16=ABSORBTIVITY
   17=BOIL              18=EXTRA NODES

   19=BLOOD             20=APL1
   21=APLN1             22=APL2
```

23=APLN2	24=ADE1	25=ADE2

18 <CR>

THE NUMBER OF EXTRA NODES IS: 0 INPUT NEW VALUE: **7 <CR>**

ENTER NEW VALUES SEPARATED BY A COMMAS, OR A <CR>
IF THE PROGRAM IS TO CALCULATE VALUES. **25.,50.,75.,100.,125.,150.,175.**

The next screen is shown below:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

```
TEMPIO =  32.5000      DENS =    1.00000        Q1 =      .40000
BL =     .22000        AK =     .01000          JINC = 12
TEMPB =   4.5000       ABSORB =     .61300      BOIL =  100.15000

PL1 =    1.46000       PLN1 = 147.37000         DE1 =     50000.0
PL2 =    2.24000       PLN2 = 239.47000         DE2 =     80000.0
ETIME =   3.02000      ITIME =  80.00000        NXTRA =  7
BLOOD =    .00100

APL1 =    .78000       APLN1 = 285.52000        ADE1 =     93534.9
APL2 =    .60000       APLN2 = 117.43000        ADE2 =     39109.8

THE EXTRA NODES ARE:  25.0  50.0  75.0  100.0  125.0  150.0  175.0
```

DO YOU WANT TO MAKE ANY CHANGES? Y OR N **Y**

Answer yes (Y) here to change the next input value using the following screen:

PICK A NUMBER

1=TEMPIO	8=ETIME
2=DENS	9=PL1
3=Q1	10=PLN1
4=BL	11=PL2
5=AK	12=PLN2
6=JINC	13=DE1
7=TEMPB	14=DE2
15=ITIME	16=ABSORBTIVITY
17=BOIL	18=EXTRA NODES
19=BLOOD	20=APL1
21=APLN1	22=APL2

23=APLN2 24=ADE1 25=ADE2

19 <CR>

THE VALUE FOR BLOOD IS: .00100 INPUT NEW VALUE: **0.0007 <CR>**

The next screen is shown below:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPIO = 32.5000	DENS = 1.00000	Q1 = .40000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.50000	ABSORB = .61300	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 3.02000	ITIME = 80.00000	NXTRA = 7
BLOOD = .00070		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

THE EXTRA NODES ARE: 25.0 50.0 75.0 100.0 125.0 150.0 175.0

DO YOU WANT TO MAKE ANY CHANGES? Y OR N **Y**

Answer yes (Y) here to change the next input value using the following screen:

PICK A NUMBER

1=TEMPIO 8=ETIME

2=DENS 9=PL1
3=Q1 10=PLN1

4=BL 11=PL2
5=AK 12=PLN2
6=JINC 13=DE1
7=TEMPB 14=DE2

15=ITIME 16=ABSORBTIVITY
17=BOIL 18=EXTRA NODES

19=BLOOD 20=APL1
21=APLN1 22=APL2

23=APLN2 24=ADE1 25=ADE2

8 <CR>

THE VALUE FOR ETIME IS: 3.02000 INPUT NEW VALUE: **5.6** <CR>

The next screen is shown below:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

```
TEMPIO =  32.5000      DENS =   1.00000        Q1 =     .40000
BL =     .22000        AK =    .01000          JINC = 12
TEMPB =   4.50000      ABSORB =    .61300      BOIL =  100.15000

PL1 =   1.46000        PLN1 = 147.37000        DE1 =    50000.0
PL2 =   2.24000        PLN2 = 239.47000        DE2 =    80000.0
ETIME =   5.60000      ITIME =  80.00000       NXTRA =  7
BLOOD =    .00070

APL1 =    .78000       APLN1 = 285.52000       ADE1 =     93534.9
APL2 =    .60000       APLN2 = 117.43000       ADE2 =     39109.8

THE EXTRA NODES ARE:  25.0  50.0  75.0  100.0  125.0  150.0  175.0

          DO YOU WANT TO MAKE ANY CHANGES? Y OR N Y
```

Answer yes (Y) here to change the next input value using the following screen:

```
PICK A NUMBER

     1=TEMPIO            8=ETIME

     2=DENS              9=PL1
     3=Q1                10=PLN1

     4=BL                11=PL2
     5=AK                12=PLN2

     6=JINC              13=DE1
     7=TEMPB             14=DE2

     15=ITIME            16=ABSORBTIVITY
     17=BOIL             18=EXTRA NODES

     19=BLOOD            20=APL1
     21=APLN1            22=APL2

     23=APLN2            24=ADE1                  25=ADE2
```

16 <CR>

THE VALUE FOR ABSORB IS: 0.61300 INPUT NEW VALUE: **0.94** <CR>

The next screen is shown below:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPIO = 32.5000	DENS = 1.00000	Q1 = .40000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.50000	ABSORB = .94000	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 5.60000	ITIME = 80.00000	NXTRA = 7
BLOOD = .00070		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

THE EXTRA NODES ARE: 25.0 50.0 75.0 100.0 125.0 150.0 175.0

DO YOU WANT TO MAKE ANY CHANGES? Y OR N **N**

At this point all of the input values for Stoll's example case have been set, so the answer here is no (N).

****

NOTE: If you inadvertently answer yes (Y) to make changes, and then decide not to make any, type a <CR> to exit the "PICK A NUMBER" menu, and the following question will appear:

DO YOU WISH TO CONTINUE? TYPE Y OR N **Y** <CR>

Type yes (Y) to continue on with the present run.

****

Now that the correct parameters are set up, select #2 to proceed:

TYPE THE NUMBER OF THE FUNCTION BELOW THAT YOU
WISH TO PERFORM.

CHOOSE A FUNCTION NUMBER:
1 - CHANGE SELECTED INITIAL VALUES
2 - NO CHANGES--CONTINUE RUNNING THE PROGRAM
3 - EXIT

PLEASE ENTER THE FUNCTION NUMBER: **2** <CR>

You are now ready to run the program. BURNSIM will ask you for some file names in which to store the data and summaries.

ENTER THE MODEL NAME OR DESCRIPTION (UP TO 80
CHARACTERS). THIS INFORMATION WILL BE USED
AS A TITLE ON THE SUMMARY PAGE.

TEST OF A. STOLL'S .4CAL 5.6 SEC CASE FOR USER'S MANUAL <CR>

The following screen appears:

NOW ENTER THE SUMMARY FILENAME (UP TO 8 CHARACTERS). THIS FILE WILL CONTAIN A SUMMARY OF THE SIMULATION. **SUM1** ⟨CR⟩

Any name up to 8 characters can be used.

The next screen then appears:

NOW ENTER THE TEMPERATURE FILE (UP TO 8 CHARACTERS). THIS FILE WILL CONTAIN A LIST OF THE TEMPERATURES AT THE VARIOUS NODES DURING THE SIMULATION. **TFILE1** ⟨CR⟩

Any name up to 8 characters can be used.

While calculating, the model prints the following on the screen:

```
  T=        XTIME=                              TIME=  0.000000
   32.50       0.0000E+00
   32.91       0.0000E+00
   33.32       0.0000E+00
   33.73       0.0000E+00
   34.14       0.0000E+00
   34.55       0.0000E+00
   34.95       0.0000E+00
   35.36       0.0000E+00
   35.77       0.0000E+00
   36.18       0.0000E+00
   36.59       0.0000E+00
   37.00       0.0000E+00
BLUD =.00000

  T=        XTIME=                              TIME=  0.010000
   32.96       0.0000E+00
   32.92       0.0000E+00
   33.32       0.0000E+00
   33.73       0.0000E+00
   34.14       0.0000E+00
   34.54       0.0000E+00
   34.95       0.0000E+00
   35.36       0.0000E+00
   35.77       0.0000E+00
   36.18       0.0000E+00
   36.59       0.0000E+00
   36.99       0.0000E+00
BLUD =.00000
```

```
  T=        XTIME=                               TIME=  1.000000
   44.40      0.0000E+00
   40.02      0.0000E+00
   37.25      0.0000E+00
   35.71      0.0000E+00
   35.03      0.0000E+00
   34.89      0.0000E+00
   35.04      0.0000E+00
   35.33      0.0000E+00
   35.67      0.0000E+00
   36.01      0.0000E+00
   36.32      0.0000E+00
   36.64      0.0000E+00
BLUD =.00003

  T=        XTIME=                               TIME=  2.000000
   49.19      0.0000E+00
   44.62      0.0000E+00
   41.24      0.0000E+00
   38.86      0.0000E+00
   37.29      0.0000E+00
   36.36      0.0000E+00
   35.90      0.0000E+00
   35.76      0.0000E+00
   35.83      0.0000E+00
   36.02      0.0000E+00
   36.27      0.0000E+00
   36.60      0.0000E+00
BLUD =.00007
.
. part of the sequence omitted to save space.
.
\/
  T=        XTIME=                               TIME= 13.000000
   44.50      0.0000E+00
   44.44      0.0000E+00
   44.32      0.0000E+00
   44.13      0.0000E+00
   43.81      0.0000E+00
   43.37      0.0000E+00
   42.81      0.0000E+00
   42.13      0.0000E+00
   41.36      0.0000E+00
   40.50      0.0000E+00
   39.59      0.0000E+00
   38.43      0.0000E+00
BLUD =.00045

  T=        XTIME=                               TIME= 14.000000
   44.02      0.0000E+00
   43.97      0.0000E+00
   43.86      0.0000E+00
```

```
   43.70       0.0000E+00
   43.43       0.0000E+00
   43.03       0.0000E+00
   42.52       0.0000E+00
   41.90       0.0000E+00
   41.17       0.0000E+00
   40.36       0.0000E+00
   39.49       0.0000E+00
   38.38       0.0000E+00
BLUD =.00049

  T=        XTIME=                                      TIME= 14.040000
   44.00       0.0000E+00
   43.95       0.0000E+00
   43.85       0.0000E+00
   43.69       0.0000E+00
   43.41       0.0000E+00
   43.02       0.0000E+00
   42.51       0.0000E+00
   41.89       0.0000E+00
   41.17       0.0000E+00
   40.36       0.0000E+00
   39.48       0.0000E+00
   38.38       0.0000E+00
BLUD =.00049
```

At the conclusion of the calculations, the following information appears on the screen:

```
    W=1 LIES ABOVE NODE 2.  INTERCOLLATING VALUES OF D
    AND W COMPUTED FROM INTERPOLATED VALUES OF D AND
    TEMPERATURE.

MAXIMUM TEMPERATURE =   60.056

THRESHOLD DEPTH =    104.6

FINAL TIME =   14.04

TIME TO PAIN =   1.59

                TYPE A <CR> TO CONTINUE.  <CR>
```

The next screen asks if you want to reformat the file so that it can be brought into the HARVARD GRAPHICS shell to make a plot.

```
     DO YOU WANT TO PLOT THE TEMPERATURE VS. TIME
     IN HARVARD GRAPHICS? Y OR N  Y <CR>
```

If you answer yes (Y) then you must type in a new file name for the HARVARD GRAPHICS temperature file.

THE TEMPERATURE DATA IS STORED IN FILE: TFILE1

ENTER THE FILE TO STORE THE HARVARD GRAPHICS
TEMPERATURES USING UP TO 12 CHARACTERS
INCLUDING THE ENDING .DAT **HGTFILE1.DAT**

The following will then appear on the next screen:

THE MODEL OUTPUT IS IN FILE: OUTFILE
USE "PRINT" OR "TYPE " AFTER YOU EXIT THE PROGRAM TO SEE IT.

THE TEMPERATURES AT EACH NODE ARE IN FILE: TFILE1
USE "PRINT" OR "TYPE " AFTER YOU EXIT THE PROGRAM TO SEE IT.

THE TEMPERATURES FOR THE HARVARD GRAPHICS PLOTS ARE IN FILE:
HGTFILE1.DAT USE "PRINT" OR "TYPE" AFTER YOU EXIT THE PROGRAM
TO SEE IT.

THE SUMMARY PRINTOUT IS IN FILE: SUM1
USE "PRINT" OR "TYPE " AFTER YOU EXIT THE PROGRAM TO SEE IT.

TYPE A <CR> TO CONTINUE. **<CR>**

The following question will appear next on the screen:

DO YOU WANT TO CONTINUE? Y OR N

At this point choosing yes (Y) takes you back to the following screen:

TYPE THE NUMBER OF THE FUNCTION BELOW THAT YOU
WISH TO PERFORM.

CHOOSE A FUNCTION NUMBER:
1 - CHANGE SELECTED INITIAL VALUES
2 - NO CHANGES--CONTINUE RUNNING THE PROGRAM
3 - EXIT

PLEASE ENTER THE FUNCTION NUMBER:

If you choose no (N) at the "DO YOU WANT TO CONTINUE?" you will see the following question:

DO YOU WANT TO DO ANOTHER RUN? Y OR N

If you answer yes (Y) you will be taken back to the following screen to change any desired input parameters:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

```
TEMPIO =  32.5000       DENS =    1.00000         Q1 =      .40000
BL =     .22000         AK =     .01000           JINC = 12
TEMPB =   4.50000       ABSORB =     .94000       BOIL =  100.15000

PL1 =   1.46000         PLN1 = 147.37000          DE1 =     50000.0
PL2 =   2.24000         PLN2 = 239.47000          DE2 =     80000.0
ETIME =   5.60000       ITIME =  80.00000         NXTRA = 7
BLOOD =    .00070

APL1 =    .78000        APLN1 = 285.52000         ADE1 =     93534.9
APL2 =    .60000        APLN2 = 117.43000         ADE2 =     39109.8

THE EXTRA NODES ARE:  25.0  50.0  75.0  100.0  125.0  150.0  175.0

        DO YOU WANT TO MAKE ANY CHANGES? Y OR N
```

If you answer no (N) to "DO YOU WANT TO DO ANOTHER RUN?", you will exit the BURNSIM program.

If you type the file SUM1 the following appears on the screen:

```
        MODEL NAME OR DESCRIPTION: TEST OF A. STOLL .4CAL 5.6SEC CASE

                            SKIN DIFFUSION DATA
                            INPUT PARAMETER LIST

    TEMPIO =    32.50000      DENS =     1.00000       Q1 =       .40000
    BL =      .22000          AK =      .01000         JINC = 12
    TEMPB =     4.50000       ABSORB =      .94000     BOIL =  100.15000

    PL1 =     1.46000         PLN1 =  147.37000        DE1 =     50000.0
    PL2 =     2.24000         PLN2 =  239.47000        DE2 =     80000.0
    ETIME =     5.60000       ITIME =   80.00000       NXTRA =  7
    BLOOD =
    APL1 =      .78000        APLN1 =  285.52000       ADE1 =     93534.9
    APL2 =      .60000        APLN2 =  117.43000       ADE2 =     39109.8

     THE EXTRA NODES ARE:   25.0  50.0  75.0 100.0 125.0 150.0 175.0

        FLUX FILE I.D.:               .00   2

 FLUX(I)=
     1    .400     2    .400

 W=           .21973E+01
 W=           .12061E+00
 W=           .14088E-01

 D=          -.16000E+02
```

D= .52983E+01
D= .59915E+01

W=1 LIES ABOVE NODE 2. INTERCOLLATING VALUES OF D AND W COMPUTED FROM INTERPOLATED VALUES OF D AND TEMPERATURE.

W= .10360E+01
W= .86923E+00
W= .73320E+00

D= .46052E+01
D= .48283E+01
D= .50106E+01

W =	.21973E+01	AT DEPTH (IN MICRONS)=	.112535E-06
W =	.18217E+01	AT DEPTH (IN MICRONS)=	25.0000
W =	.14992E+01	AT DEPTH (IN MICRONS)=	50.0000
W =	.12423E+01	AT DEPTH (IN MICRONS)=	75.0000
W =	.10360E+01	AT DEPTH (IN MICRONS)=	100.000
W =	.86923E+00	AT DEPTH (IN MICRONS)=	125.000
W =	.73320E+00	AT DEPTH (IN MICRONS)=	150.000
W =	.62140E+00	AT DEPTH (IN MICRONS)=	175.000
W =	.12061E+00	AT DEPTH (IN MICRONS)=	200.000
W =	.14088E-01	AT DEPTH (IN MICRONS)=	400.000
W =	.47704E-02	AT DEPTH (IN MICRONS)=	600.000
W =	.21844E-02	AT DEPTH (IN MICRONS)=	800.000

MAXIMUM TEMPERATURE = 60.056

THRESHOLD DEPTH = 104.6

FINAL TIME = 14.04

TIME TO PAIN IS 1.59 SECONDS.

If you plot the data saved in TFILE1 and overlay Stoll's measured data, we get the following:

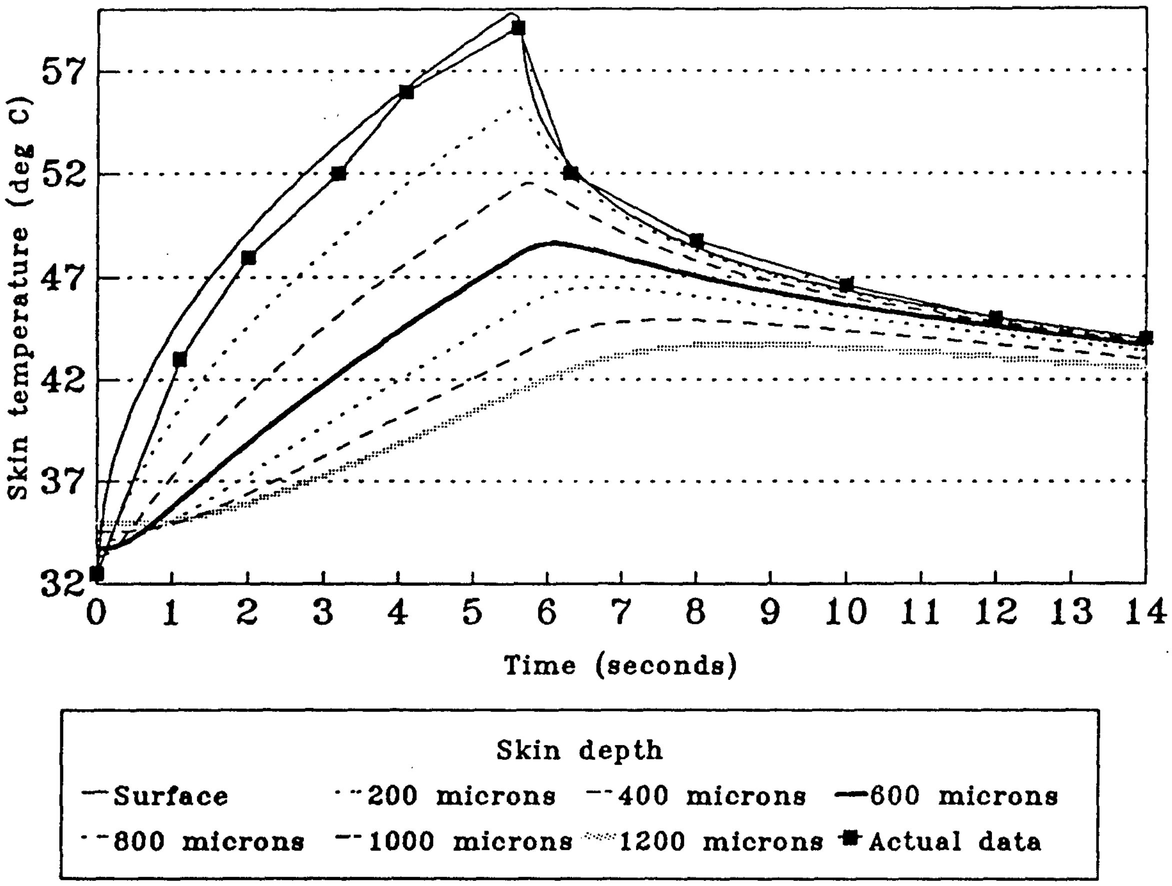

Figure 3. Skin temperatures at first six nodes calculated with Burnsim for Stoll's Data

Notice that there is reasonable fit between the computed temperature profiles and the recorded temperature. The predicted depth is 104.9 microns. Stoll observed a threshold blister, hence the damage should be between 80μm and 120μm.

Helpful hints

This section is devoted to explaining the inputs to the model and some hints about how to set up the model for special cases. The inputs are summarized in Table A-1.

There are nine special cases which have been found by previous users. First, for short exposures of less than 1 second, change the calculation interval (AK) from its normal value of .01 second to some value which is at least 100 times less than the duration. Thus, for an

exposure of 0.1 sec use AK = 0.001 second. Second, if the skin has been blackened, e.g., with india ink, use an absorptivity of about 0.92 to 0.94. Third, the default value of 0.613 for absorptivity assumes that 100 percent of the convective energy is absorbed, only 60 percent of the radiative energy is absorbed, and 5 percent of incident radiation is intercepted by hair. Thus, assuming

1) Q incident = 0.1 qi (convective) + 0.9 qi (radiative)
2) 5 percent radiative is not absorbed because of hair stubble,

then Q = 0.1 qi + 0.6(.9)(.95)qi = 0.613 qi

Fourth, use NXTRA 7 especially for mild exposures so that shallow burn depths are calculated more accurately. Fifth, a value of 0.0007 for Blood works best for shallow human burns.

Sixth, new values for DE1, DE2, PL1, PLN1, PL2, and PLN2 can be calculated if you wish to try rate constants published by other authors (see model derivation in Appendix A).

Seventh, it is possible to calculate new thermal properties based on humidity changes. Read the paper on thermal properties published in the journal Burns (Knox et al. 1986).

Eighth, the model currently assumes that ambient temperature is 23.9°C. Thus, during cool down the surface loses heat to a 23.9°C environment. This number can be changed only in the source code in the following line:

```
If (TIME.GE.ETIME)Q1 = -5.E-4*(t(1)-23.9)
```

Nine, for very severe exposures, where water boils in more than the first node, the thermal property recalculations routine causes an instability in the cool down phase. This can be seen if the data are plotted and can be avoided by setting the boil temperature to a much higher value. A permanent fix for this bug will appear in the next version of BURNSIM.

References

Crank, J., and Nicholson, P. 1947. Proceedings Cambridge philoslogical society. 43:50

Henriques, F. C. 1947. Studies of thermal injury. V. The predictability and the significance of thermally induced rate processes leading to irreversible epidermal injury. Archives of pathology. 43:489-502.

Knapp, S. C., and Knox, Francis, S. III. 1982. Human response to fire and personnel protection measures. AGARD/NATO Pep lecture series no. 123 on "Aircraft Fire Safety", 7-16 June, at Oslo, Norway, London, England and Washington, D.C.

Knox, F. S., III, Wachtel, T. L., and Knapp, S. C. 1978a. How to measure the burn-preventive capability of nonflammable textiles: A comparison of the USAARL porcine bioassay technique with mathematical models. Burns. 5(1):19-29. Also reprinted as USAARL Report No. 79-5. 1979. (Uses model and sensor output to predict burns.)

Knox, F. S., III, Wachtel, T. L., and Knapp, S. C. 1978b. Biomedical constraints on thermal protective flight clothing design: A bio-engineering analysis. In Operational helicopter aviation medicine: AGARD/NATO Panel Specialists' Meeting, May 1-5; Fort Rucker, AL. London: Technical Editing and Reproduction Ltd. pp. 63-1--63-11. AGARD-CP-255.

Knox, F. S., III, Wachtel, T. L., and Knapp, S. C. 1978c. Mathematical models of skin burns induced by simulated postcrash fires as aids in ther- mal protective clothing design and selection. In Proceedings of the army science conference, June 20-22; West Point, NY, 267-281. Vol II (AD-A056437). Also published as USAARL Report No. 78-15.

Knox, F. S., III, Knapp, S. C., McCahan, G. R., Jr., and Wachtel, T. L. 1979. Bioassay of thermal protection afforded by candidate flight suit fabrics. Journal of aviation, space, and environmental medicine. 50(10):1023-1030.

Knox, F. S., III. 1979. Predictability of burn depth: Data analysis and mathematical modeling based on USAARL's experimental porcine burn data. Shreveport, LA: Louisiana State University School of Medicine, Department of Physiology and Biophysics. Contract DAMD17-77-7004.

Knox, F. S., III, Wachtel, T. L., and Knapp, S. C. 1980. Burn prediction model for thermally protective clothing evaluation. Paper presented at the annual meeting of the Aerospace Medical Association, 12-15 May.

Knox, F. S., III, Wachtel, T. L., McCahan, G. R., Jr., and Knapp, S. C. 1986. Thermal properties calculated from measured water content as a function of depth in porcine skin. Burns. 12(8):556-562.

Mehta, A., and Wong, F. 1973. Measurement of flammability and burn potential of fabrics. (Summary report December 1971-January 1973.) Cambridge, MA: Fuels Research Laboratory, Massachusetts Institute of Technology Project DSR 73884.

Moritz, A. R. 1947. Studies of thermal injury. III. The pathology and pathogenesis of cutaneous burns, an experimental study. American journal of pathology. 23:915-941.

Morse, H. L., Thompson, J. G., Clark, K. J., Green, K. A., and Moyer, C. B. 1973. Analysis of the thermal responses of protective fabrics. Wright-Patterson Air Force Base, OH: Air Force Materials Laboratory, Air Force Systems Command. Technical Report AFML-TR-73-17.

Reneau, D. D., and O'Young, Nelson. 1976, 1977, 1978. Consultation report to F. S. Knox. Shreveport, LA: Louisiana State University Medical Center, Department of Physiology and Biophysics. U.S. Army Contract Nos. DABT01-75-C-0257 and DAMD-17-77-C-7004.

Rushmer, R. F., Buettner, K. J. K., Short, J. M., and Odland, G. F. 1966. The skin. Science. 154(3747):343-348.

Stoll, A., and Greene, L. C. 1959. Relationship between pain and tissue damage due to thermal radiation. Journal of applied physiology. 14:373.

Stoll, A. M., and Chianta, M. A. 1971. Heat transfer through fabrics as related to thermal injury. Transactions-New York academy of science. Vol 33(7):649-670. November.

Takata, A. 1974. Development of criterion for skin burns. Aerospace medicine. 45(6):634-637.

Weaver, J. A., and Stoll, A. M. 1969. Mathematical model of skin exposed to thermal radiation. Aerospace medicine. 40:24-30.

Bibliography

Albright, J. D., Knox, F. S. III, DuBois, D. R., and Keiser, G. M. 1971a. The testing of thermal protective clothingin a reproducible fuel fire environment, phase I report: a feasibility study. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL LR 71-3-3-2.

Albright, J. D., Knox, F. S. III, DuBois, D. R., and Keiser, G. M. 1971b. The testing of thermal protective clothing in a reproducible fuel fire environment, a feasibility study. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 71-24. (Defines postcrash fire environment and assesses the proper directions of future research.)

Anderson, W. A. D. 1966. Pathology. 5th ed., Vol. 1. St. Louis, MO: The C.V. Mosby Company.

Archanbeau, J. O., Fairchild, R. G., and Commerford, S. L. 1966. Response of skin of swine to increasing exposure of 250-KVP X-ray. In: Bustad, L.K. and McClellan, R.O., ed. Swine in biomedical research. Seattle: Frayn. 463.

Armed Forces Institute of Pathology. AFIP manual of histologic and special staining technique. 2d ed. New York: Blackstone Division of McGraw Hill Book Company.

Artz, C. P., and Moncrief, J. A. 1969. The treatment of burns. 2d ed. Philadelphia, PA: W.B. Saunders Company.

Bader, B. E. 1965. Heat transfer in liquid hydrocarbon fuel fires. In: Chemical Engineering Progress Symposium Series. pp. 78-90. Vol. 61, No. 56. Sandia Albequerque, NM.

Basar, Erol. 1976. The circulatory autoregulation. In: Biophysical and physiological systems analysis. Reading, MA: Addison-Wesley Publishing Company. Chapter 4.

Belason, P. H., Castle, G., Crowley, D., and D'Auanzo, L. 1970. A fire simulation facility for materials response testing. Fire technology. 15(3).

Berkley, K. M. 1954. Evaluation of surface appearance of burns by depth of damage. Rochester, NY: University of Rochester. Atomic Energy Report UR-337.

Berkley, K. M., Pearse, H. E., and Davis, T. P. 1954. Studies of flash burns: the influence of skin temperature in the production of cutaneous burns in swine. Rochester, NY: University of Rochester. Atomic Energy Project UR-338.

Berkley, K. M. 1957. The effect of air space on sub-fabric burns in swine. Rochester, NY: The University of Rochester. Atomic Energy Project UR-490.

Billote, J. B., Coumans, R. J. K., Guthy, E. A., Constable, J. D., and Burke, J. F. 1969. Effect of topical sulfamylon on wound healing. Surgical forum. 20:71.

Blinov, V. I., and Khuiakov, G. N. 1957. Certain laws governing the diffusive burning of liquids. Academic Nauk, SSSR Doklady. 113:1094-1098. (Reviewed by H.C. Hottel, 1959, Fire research abstracts and reviews 1, pp 41-44.)

Bruce, G. H., Peaceman, D. W., Rackford, H. H., and Rice, J. D. 1953. Transactions American institute of mining, metallurgical and petroleum engineers. 198:79.

Buettner, K. 1952. Effects of extreme heat and cold on human skin. III. Numerical analysis and pilot experiments on penetrating flash radiation effects. Journal of applied physiology. 5(5):207-220.

Burgess, D. S., Grumer, J., and Wolfhard, H. G. 1961. Burning rates of liquid fuels in large and small open trays. In: Berl, W. G., ed. The use of models in fire research. Publication. 786. Washington, DC: National Academy of Sciences - National Research Council. 68-75.

Bustad, L. K; 1966, Pigs in the laboratory. Scientific American. 214:94.

Bustad, L. K., and McClellan, R. O., ed. 1966. Swine in biomedical research. Seattle, WA: Frayn.

Butterfield, W. S. H., and Dixey, J. R. B. 1951. Burns from atomic bombs, Journal royal naval medical science. 37:9.

Callen, H. B. 1960. Thermodynamics. New York, NY: John Wiley & Sons, Inc.

Carhart, W. H., and Affens, W. A. 1969. Flammability of aircraft fuels. Fire technology. 5(1):16.

Carslaw, H. S., and Jaeger, J. C. 1959. Conduction of heat in solids. Oxford, Oxford Press University. QC 321.C28

Conley, D. W. 1965. Post-crash fire-fighting studies on transport category aircraft. Atlantic City, NJ: Federal Aviation Agency. Report RD-65-50.

Cooper, T. E., and Trezek, G. J. 1971. Correlation of thermal properties of some human tissue with water content. Journal of aerospace medicine. 42(1):24-27.

Crank, J., and Nicholson, P. 1947. Proceedings Cambridge philoslogical society. 43:50.

Dalzell, W. H., and Sarofim, A. F. 1969. Optical constants of soot and their application to heat-flux calculations. Journal of heat transfer transactions of the American society of mechanical engineers. 100-104.

Derksen, W. L., Delhevy, G. P., and Monahan, T. I. 1960. Thermal and optical properties of the NML skin stimulant. New York, NY: Naval Materials Laboratory, New York Naval Shipyard. Laboratory Project 5046-3.

Diller, K. R. 1985. Analysis of skin burns. In Shitzer A., Eberhart, R. C. eds: Heat transfer in medicine and biology: Analysis and applications, Vol 2. New York: Plenum Publishing Co. 85-134.

Dumphy, J. E. 1966. Whither repair? In: Levenson, S. M., Stein, J. M., and Grossblatt, N. eds, Wound healing: Proceedings of workshop. Washington, DC: National Academy of Sciences, National Research Council. p. 4.

Emmons, H. W. 1961. Some observations on pool burning. In: Berl, W. G., ed, The use of models in fire research. Washington, DC: National Academy of Sciences - National Research Council. Publication 786. 50-67.

Emmons, H. W. 1964. Fundamental problems of the free burning fire. Tenth symposium (international) on combustion. pp. 951-964. Combustion Institute, Pittsburgh, PA.

Evans, E. I., Brooks, J. W., Schmidt, F. H., Williams, R. C., and Ham, W. T. 1955. Flash burn studies on human volunteers. Surgery. 37:280.

Feller, I., Flora, J. D., and Bawol, R. 1976. Baseline results of therapy for burned patients. Journal of the American medical association. 236:(17):1943-1947.

Feller, I., Richards, K., and Crane, K. 1972. The role of flammable fabrics in severe burn injuries. In: Proceedings of the sixth annual meeting of the information council on fabric flammability. Hotel Commodore, 7 December, New York, NY.

Fisher, J. C., Wells, J. A., and Fulwider, B. T. 1977. Do we need a burn severity grading system? Journal of trauma. 17:252.

Forbes, P. D. 1969. Vascular supply of the skin and hair in swine. In: Montag, W., and Dobson, R. L., eds. Hair growth, advances in biology of skin. Oxford, MA: Pergamon. 9, 479.

Fowler, J. F. 1963. Experiments with fractionated X-ray treatment of the skin of pigs. British journal of radiology. 36:188-196.

Gaydon, A. G., and Wolfhard, H. G. 1960. Flames, their structure, radiation and temperature. London: Chapman and Hall Ltd.

Gillman, T., and Ordman, L., 1966. Histogenesis of healing incised and excised wounds in young pigs. In: Bustad, L.K., and McClellan, R.O., eds. Swine in biomedical research. Seattle, WA: Frayn. p. 299.

Gordon, W., and McMillen, R. D. 1965. Temperature distribution within aircraft-fuel fires. Fire technology. 1(1):52.

Grillo, H. D. 1966. Open wounds as an experimental system. In: Levenson, S. M., Stein, J. M., and Grossblatt, N., eds. Wound healing: Proceedings of a workshop. Washington, DC: National Academy of Sciences - National Research Council. pp. 261-269.

Griswold, J. 1946. Fuels, combustion, and furnaces. New York, NY: McGraw-Hill.

Hardy, J. D. 1962. Physiological effects of high intensity infrared heating. American society heating and refrigeration engineers journal.

Hardy, J. D., and Soderstrom, G. F. 1938. Heat loss from the nude body and peripheral blood flow at temperature of 22° to 35°C. Journal of nutrition. 16:493.

Henriques, F. C. 1947. Studies of thermal injury. V. The predictability and the significance of thermally induced rate processes leading to irreversible epidermal injury. Archives of pathology. 43:489-502.

Henriques, F. C., and Moritz, A. R. 1947. Studies of thermal injury. I. The condition of heat to and through skin and the temperatures attained therein. A theoretical and an experimental investigation. American journal of pathology. 23:531-549.

Hinshaw, J. R. 1963. Progressive changes in the depth of burns. Archives of surgery. 87:993-997.

Hinshaw, J. R., and Payne, F. W. 1963. The restoration and remodeling of the skin after a second degree burn. Surgery, gynecology and obstetrics. 117:738-744.

Hirschfelder, J. O. 1962. Some remarks on the theory of flame propagation. Ninth symposium (international) on combustion. Combustion Insitute, Pittsburgh, PA. pp. 553-559.

Jobb, K. Y. F., and Kennedy, P. C. 1970. Pathology of domestic animals. 2d ed., Vol. 2. New York, NY: Academic Press.

Karasek, J., and Oehlert, W. 1968a. Die ultrastruktur der epidermis des schweines. I. Stratum basale und stratum spinosum. Zeitschrift fuer mikroskopische anatoische forschung. 78:133.

------. 1968b. Die ultrastruktur der epidermis des schweines. II. Stratum granulsoum and corneum. Zeitschrift fuer mikroskopische anatoische forschung. 79:157.

Knapp, S. C., Allemond, P. A., and Karney, D. H. 1978. Helicopter crashworthy fuel systems and their effectiveness in preventing thermal injury. In: Operational helicopter aviation medicine: AGARD/NATO Panel Specialists' Meeting, May 1-5; Fort Rucker, AL. London: Technical Editing and Reproduction Ltd. pp. 61-1-61-7. AGARD-CP-255.

Knapp, S. C., and Knox, F. S., III. 1982. Human response to fire and personnel protection measures. AGARD/NATO PEP lecture series no. 123 on "Aircraft fire safety." 7-16 June, at Oslo, Norway, London, England, and Washington, D.C.

Knox, F. S., III, McCahan, G. R., Jr., Wachtel, T. L., Trevethan, W. P., Martin, A. S., DuBois, D. R., and Keiser, G. S. 1971. Engineering test of lightweight underwear of the winter flight clothing system: Thermal protection. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 71-19.

Knox, F. S., III. 1971. Protective clothing for aviators. Presented at the Third U.S. Army Aviation Accident Prevention Conference; August 18-19; Fort Rucker, AL.

------. 1972a. Preliminary results, conclusions and recommendations from the evaluation of helmet flammability - DH-132 and T56-6 helmets. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL LR-72-17-3-5.

------. 1972b. Realistic evaluation of fabrics for thermal protective clothing. Presented to the Survival and Flight Equipment Association 10th Annual Symposium; October 2-5; Phoenix, AZ.

Knox, F. S., III, McCahan, G. R., Jr., and Wachtel, T. L. 1972. The use of the pig as a bioassay substrate for evaluation of thermal protective clothing and physical sensor calibration. Presented at the Eighth Scientific Session of the Joint Committee on Aviation Pathology; October 8-12; Colorado Springs, CO. Also presented at the American Burn Association 5th Annual Meeting; 1973 April 6; Dallas, TX (16mm color, sound film, 20 min.). Published in Journal of aerospace medicine. 45:933, 1974.

Knox, F. S., and Bailey, R. W. 1973. Results, conclusions and recommendations from the evaluation of helmet flammability - DH-132 and T56-6 helmets. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL LR-73-9-3-4.

Knox, T. (F. S., III), and Knapp, S. C. 1975. Testing for thermal protection. Presented at the 4th National Flame-Free Design Conference; March 11-13; San Diego, CA.

Knox, F. S., III, and Nockton, R. A. 1976. Data analysis and mathematical modeling based on U.S. Army Aeromedical Research Laboratory's experimental porcine burn - Phase I data. 1 July 1975 - 30 September 1976. Shreveport, LA: LSU School of Medicine, Department of Physiology and Biophysics. Contract No. DABT01-75-C-0257.

Knox, F. S., III, Wachtel, T. L., and Knapp, S. C. 1978a. How to measure the burn-preventive capability of nonflammable textiles: A comparison of the USAARL porcine bioassay technique with mathematical models. Burns. 5(1):19-29. Also reprinted as USAARL Report No. 79-5. (Uses model and sensor output to predict burns.)

------. 1978b. Biomedical constraints on thermal protective flight clothing design: A bio-engineering analysis. In: Operational helicopter aviation medicine: AGARD/NATO Panel Specialists' Meeting, May 1-5; Fort Rucker, AL. London: Technical Editing and Reproduction Ltd. pp. 63-1--63-11. AGARD-CP-255.

------. 1978c. Mathematical models of skin burns induced by simulated postcrash fires as aids in thermal protective clothing design and selection. In: Proceedings of the army science conference; June 20-22; West Point, NY. pp. 267-281. Vol. II (AD-A056437). Also published as USAARL Report No. 78-15.

Knox, F. S., III, Wachtel, T. L., and McCahan, G. R., Jr. 1978. Evaluation of four thermally protective fabrics using the USAARL bioassay method. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 78-9.

Knox, F. S., III, Wachtel, T. L., Trevethan, W. P., McCahan, G. R., Jr., and Brown, R. J. 1978. A porcine bioassay method for analysis of thermally protective fabrics: A histological and burn depth grading system. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 78-11.

Knox, F. S., III, Wachtel, T. L., McCahan, G. R., Jr., and Knapp, S. C. 1978. A porcine bioassay study of the physiological effects of fiber and dye degradation products (FDP) on burn wound healing. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 78-10. Also published as The effect of fiber and dye degradation products (FDP) on burn wound healing. Journal of aviation, space, and enviornmental medicine. October, pp. 1007-1015.

Knox, F. S., III, Knapp, S. C., McCahan, G. R., Jr., and Wachtel, T. L. 1979. Bioassay determination of thermal protection afforded by candidate flight suit fabrics. Journal of aviation, space and environmental medicine. 50(10):1023-1030.

Knox, F. S., III. 1979a. VIPER exhaust burn hazard. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL LR-79-9-1-1. (Application of the model BRNSIM to assess the hazard associated with exposure to hot gases.)

Knox, F. S., III. 1979b. Predictability of burn depth: Data analysis and mathematical modeling based on USAARL's experimental porcine burn data. Shreveport, LA: Louisiana State University School of Medicine, Department of Physiology and Biophysics. Contract DAMD17-77-7004.

Knox, F. S. III, Sauermilch, P. W., Wachtel, T. L., McCahan, G. R., Jr., Trevethan, W. P., Lum, C. B., Brown, R. J., and Alford, L. A. 1979. A fire simulator/shutter system for testing protective fabrics and calibrating thermal sensors. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 79-4.

Knox, F. S., III, Wachtel, T. L., and Knapp, S.C. 1980. Burn prediction model for thermally protective clothing evaluation. Presented to the Aerospace Medical Association; 12-15 May; Anaheim, CA.

Knox, F. S., III, Wachtel, T. L., McCahan, G. R., Jr., and Knapp, S. C. 1986. Thermal properties calculated from measured water content as a function of depth in porcine skin. Burns. 12(8):556-562.

Kreith, F. 1965. Principles of heat transfer. 2d ed. Scranton, PA: International Textbook Company. Chapter 4.

Lewis, B., and von Elbe, E. 1947. Temperature: Its measurement and control in science and industry. American Institute of Physics. New York, NY: Reinhold Publishing Corp.

Lewis, B., Pease, R. N., and Taylor, H. S. 1956. Combustion processes. Vol. II, High speed aerodynamics and jet propulsion. Princeton University Press.

Lipkin, M., and Hardy, J. D. 1954. Measurement of some thermal properties of human tissues. Journal of applied physiology. 7(2):212-217.

Lum, C. B. 1972. Trip report: Microscopic burn damage data - consultation with Dr. Walter Trevethan. Pensacola, FL: Naval Aerospace Medical Institute; November 27-28.

Lum, C. B. 1973. Instrumented helicopter burn. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL LR-73-6-3-2.

Lyon, J. L., Davis, T. P., and Pearse, H. E. 1955. Studies of flash burns: The relation of thermal energy applied and exposure time to burn severity. Rochester, NY: University of Rochester. Atomic Energy Report 394.

Lyon, J. L., Emery, A. J., Jr., Pearse, H. E., and Davis, T. P. 1955. Rochester, NY: University of Rochester. Atomic Energy Project Report UR-401.

Madden, J. E., Edlich, R. F., Prusak, M., and Wangensteen, O. H. 1971. The molecular basis for the antiseptic activity of rosaniline dyes in the contaminated wound. Surgical forum. 22:63.

Maggio, R. C. 1956. A molded skin stimulant material with thermal and optical constants approximating those of human skin. New York, NY: Naval Materials Laboratory, New York Naval Shipyard. Laboratory Project 5046-3. Part 105.

Magnus, G. 1961. Tests on combustion velocity of liquid fuels and temperature distribution in flames and beneath surface of the burning liquid. In: Berl, W. G., ed. The use of models in fire research. Publication 786. Washington, DC: National Academy of Sciences - National Research Council.

Marcarian, H. Q., and Calhoun, M. L. 1966. Microscopic anatomy of the integument of adult swine. American journal of veterinary research. 27:765.

McCahan, G. R., Jr., and Wachtel, T. L. 1972. Anesthesia or immobilization of domestic and miniature swine--methods and some problems. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 73-6.

McClellan, P. O. 1968. Application of swine in biomedical research. Laboratory animal care. 18:120.

McCoy, J. A., Micks, D. W., and Lynch, J. B. 1968. Discriminant function probability model for predicting survival in burned patients. Journal of the American medical association. 203:644-646.

Mehta, A., and Wong, F. 1973. Measurement of flammability and burn potential of fabrics. (Summary Report December 1971 - January 1973.) Cambridge, MA: Fuels Research Laboratory, Massachusetts Institute of Technology Project DSR 73884.

Meyer, W., and Neurand, K. 1976. The distribution of enzymes in the skin of the domestic pig. Laboratory animals. 10:347.

Mixter, G., and Pearse, H. E. 1953. Studies of flash burns: The protection afforded by 2, 4 and 6 layer fabric combinations. Rochester, NY: The University of Rochester. Atomic Energy Project UR-261.

Moncrief, J. A. 1969. Burns. In Schwartz, S. I., ed. Principles of surgery. New York, NY: McGraw-Hill, Inc. pp. 205-206.

Montagna, M., and Yun, J. S. 1964. Skin of the domestic pig. Journal of investigative dermatology. 43:11.

Montagna, W., and Yun, J. S. 1964. The skin of the domestic pig. Journal international college of surgeons. 42:11-21.

Moritz, A. R. 1947. Studies of thermal injury. III. The pathology and pathogenesis of cutaneous burns, an experimental study. American journal of pathology. 23:915-941.

Moritz, A. R., and Henriques, F. C. 1947. Studies of thermal injury. II. The relative importance of time and surface temperature in the causation of cutaneous burns. American journal of pathology. 23:695-720.

Moritz, A. R., Henriques, F. C, Dutra, F. R., and Weisiger, J. R. 1947. Studies of thermal injury, IV, and exploration of the casualty - producting attributes of conflagrations, local and systemic effects of general cutaneous exposure to excessive circumambient (air) and circumradiant heat of varying duration and intensity. Archives of pathology. 43:466-488.

Morse, H., Tichner, G., and Brown, R. 1975. Burn damage and burn depth criteria. Acurea Corp, Mountain View, CA. Aerotherm TN-75-26.

Morse, H. L., Thompson, J. G., Clark, K. J., Green, K. A., and Moyer, C. B. 1973. Analysis of the thermal responses of protective fabrics. Wright-Patterson Air Force Base, OH: Air Force Materials Laboratory, Air Force Systems Command. Technical Report AFML-TR-73-17.

Morton, B. R. 1964. Modeling fire plumes. Tenth symposium (international) on combustion. Combustion Institute, Pittsburgh, PA. pp. 973-982.

Morton, J. H., Kingsley, H. D., and Pearse, H. E. 1952. Studies on flash burns: threshold burns. Surgery, gynecology, and obstetrics. 94:317.

Moserova, J., Behounkova, E., and Prouza, Z. 1975. Subcutaneous temperature measurements in a thermal injury. Burns. 1:267.

Neill, D. T., Welker, J. R., and Shepcevich, C. M. 1970. Direct contact heat transfer from buoyant diffusion flames. Journal of fire and flammability. 1:289-300.

Nielsen, H. J., and Tao, L. N. 1964. The fire plume above a large free-burning fire. Tenth symposium (international) on combustion. Combustion Institute, Pittsburgh, PA. pp. 965-972.

Pavshkin, Y. M. 1962. The chemical composition and properties of fuels for jet propulsion. New York, NY: Pergamon Press.

Peacock, E. E., Jr., and Van Winkle, W., Jr. 1970. Surgery and biology of wound repair. Philadelphia, PA: W.B. Saunders Co.

Perkins, J. B., Pearse, H. E., and Kingsley, H. D. 1951. Studies on flash burns: The relation of the time and intensity of applied thermal energy to the severity of burns. Rochester, NY: University of Rochester. Atomic Energy Project Report UR-217.

Pesman, G. J. September 1953. Appraisal of hazards to human survival in airplane crash fires. National Advisory Committee for Aeronautics Technical Note 2996, Washington DC.

Pinkel, I. I., Preston, G. M., and Pesman, G. J. August 1952. Mechanism of start and development of aircraft crash fires. National Advisory Committee for Aeronautics Research Memorandum E52F06, Washington DC.

Ragan, H. A., and Gillis, M. F. 1975. Restraint, venipuncture, endotracheal intubation and anesthesia of miniature swine. Laboratory animal sciences. 25:409-419.

Ragozin, N. A. 1961. Jet propulsion fuels. New York, NY: Pergamon Press.

Reneau, D. D., and O'Young, N. 1976, 1977, 1978. Consultation report to F. S. Knox. Shreveport, LA: Louisiana State University Medical Center, Department of Physiology and Biophysics. U.S. Army Contract Nos. DABT01-75-C-0257 and DAMD-17-77-C-7004.

Robb, H. J. 1967. Dynamics of the microcirculation during a burn. Archives of surgery. 94:776.

Rushmer, R. F., Buettner, K. J. K., Short, J. M., and Odland, G. F. 1966. The skin. Science. 154(3747):343-348.

Scapicchio, A. P., Constable, J. D., and Opitz, B. F. 1967. Comparative effects of silver nitrate and sulfamylon acetate on epidermal regeneration. Surgical forum. 18:510.

Spalding, D. B. 1962. The art of partial modeling. Presented at the Colloquium on Modeling Principles, Ninth Symposium (international) on Combustion. Combustion Institute, Pittsburgh, PA. pp. 833-842.

Stanton, R. M., Schulman, S., and Ross, J. H. 1973. Evaluation of PBI and Nomex II for Air Force flight suits. Air Force Material Laboratory, Wright-Patterson AFB, Ohio. Technical Report AFML-TR-73-28.

Stoll, A. M., and Hardy, J. D. 1950. Study of thermocouples as skin thermometers. Journal of applied physiology. II:532-543.

Stoll, A., and Greene, L. C. 1959. Relationship between pain and tissue damage due to thermal radiation. Journal of applied physiology. 14:373.

Stoll, A. M. 1962. Thermal protection capacity of aviator's textiles. Aerospace medicine. 846-850.

Stoll, A. M., and Chianta, M. A. 1969. Method and rating system for evaluation of thermal protection. Aerospace medicine. 40(11):1232-1237.

Stoll, A. M., and Chianta, M. A. 1970. Heat transfer through fabrics, Warminster, PA: Naval Air Development Center, Aerospace Medical Department. NADC-MR-7017.

Stoll, A. M., and Chianta, M. A. 1971. Heat transfer through fabrics as related to thermal injury. Transactions-New York Academy of Sciences. Vol 33(7) Nov. 649-670.

Stoll, A. 1978. Comments made during thermal protective clothing ad hoc working conference (tri-service). Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory; April 3-4.

Takata, A. N. 1957. Unpublished data prepared by Armour Research Foundation for Air Force Special Weapons Program (AFSWP-1060), Illinois Institute of Technical Research Institution, Chicago, IL.

Takata, A. N., Rouse, J., and Stanley, T. 1973. Thermal analysis program. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. Report No. IITRI-J6286. Contract No. DA13C01-G-0309.

Takata, A. 1974. Development of criterion for skin burns. Aerospace medicine. 45(6):634-637.

Thring, M. W. 1952. The science of flames and furnaces. New York, NY: John Wiley and Sons, Inc.

Torres, M., and Buchan, M. 1972. Crashworthy fuel system mishap data. Aviation digest. pp. 44-45.

Van Wylen, J. G., and Sonntag, R. E. 1960. Fundamentals of thermodynamics. New York, NY: John Wiley & Sons, Inc.

Vincenti, W. G., and Kruger, C. H., Jr. 1965. Introduction to physical gas dynamics. New York, NY: John Wiley & Sons, Inc. Chapter XI.

Wachtel, T. L., and McCahan, G. R., Jr. 1973. A comparison of methods of preparing porcine skin for bioassay of thermal injury. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 73-9.

Wachtel, T. L., McCahan, G. R., Jr., and Monafo, W. W., Jr. 1977. Fluid resuscitation in a porcine burn shock model. Journal of surgical research. 23:405-414.

Wachtel, T. L., Knox, F. S., III, and McCahan, G. R., Jr. 1977. Methods of preparing porcine skin for bioassay of thermal injury. Military medicine. 141:536-538.

Wachtel, T. L., Knox, F. S. III, and McCahan, G. R., Jr. 1978. A porcine bioassay method for analysis of thermally protective fabrics: A clinical grading system. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 78-8.

Waldron, E. T., Smith, W. F., and Mahen, M. E. 1967. Effectiveness of aviators' garments in protecting against gasoline fires. Natick, MA: U.S. Army Natick Laboratories.

Waldron, E. T., Smith, W. F., and Mahen, M. E. The protection provided by winter aviators' garments during escape through JP-4 fuel fires. Natick, MA: U.S. Army Natick Laboratories. In press.

Weaver, J. A., and Stoll, A. M. 1969. Mathematical model of skin exposed to thermal radiation. Aerospace medicine. 40:24-30.

Weinstein, G. D. 1966. Comparison of turnover time of keratinous protein fractions in swine and human epidermis. In: Bustad, K.L., and McClellan, R.O., eds. Swine in biomedical research. Seattle, WA: Frayn.

Zilioli, A. E. 1971a. Crash injury economics: The costs of training and maintaining on Army aviator. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 71-17.

------. 1971b. Crash injury economics: Aircrewman injury and death costs occurring in UH-1 Army aircraft accidents in fiscal year 1969. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 71-18.

Appendix A

ANALYTICAL MODEL

Several years ago Weaver and Stoll (1969) proposed an extension of Stoll's earlier model (Stoll and Greene, 1959) to heat fluxes higher than those used in obtaining the experimental data upon which the earlier model had been based. They also found that the effective conductivity changed during the exposure and subsequent cooldown period. Takata (1974), using preliminary data from USAARL's Thermal Project (the uncorrected version of the current data base), formulated a model which not only predicted threshold burns but deep burns and tissue water boiling as well. Building on the work of Henriques (1947), Stoll and Greene (1959), Weaver and Stoll (1969), Mehta and Wong (1973) and Takata (1974), an analytical model was formulated as follows:

For the thermal exposure of interest, skin is essentially opaque to thermal radiation and can be considered to transfer energy internally by conduction only, since exposure durations are no longer than the minimum response times reported for increased thermoregulatory system activity (1954). Consequently, thermal energy transfer in skin can be described by the heat conduction or Fourier equation be written as follows:

$$\rho \; Cp\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right)+q \qquad (1)$$

where,

ρ = density, gm/cm^3

Cp = heat capacity, cal/gm-°C

K = thermal conductivity, cal/cm-sec-°C

T = temperature, °C

x = distance, cm

q = energy source, for the first nodal volume, cal/cm^3-sec

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[1]Simplifying assumption base on the predominance of the radiate mode of heating. May be less valid with fabrics. In actuality a correction is made to q to account for convective heating, surface absorptivity, and attenuation of radiant heating by hair.

Since skin is considered to be opaque to radiant energy from a post crash fire, and since the source term is due only to radiant energy[1], equation (1) applies only to the surface of the skin. For all conditions in which x > 0, equation (1) reduces to the following:

$$\rho \; Cp\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right) \tag{2}$$

Solution of equation (1) and (2) requires two boundary conditions for x, preferably at x = 0 and x = L, and initial conditions at t = 0 for all positions 0 < x < L. If one assumes that there is no backward flux of thermal energy at x = 0 (all conduction is into the skin), then the energy flux at x = 0 is zero and, consequently, $\partial T/\partial x = 0$. Similarly, if the problem assumes that an adiabatic backwell condition prevails at x = L, the fatty tissue, then the net flux out of the system at x = L is 0, or $\partial T/\partial x = 0$. These two boundary conditions indicate that the system is closed and that all thermal energy added to the system, $0 \le x \le L$, is distributed within the system and cannot escape.

Initial conditions are established by specifying a uniform temperature for all locations, $0 \le x \le L$ at time t = 0.

Consequently, the system may be defined by the following mathematical model:

$$\rho \; Cp\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right)+q \qquad @\; x=0 \;\; :surface \tag{3a}$$

$$\rho \; Cp\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right) \qquad @\; 0\le x\le L \tag{3b}$$

T_x = CORE TEMPERATURE = TEMPIO + TEMPB

$$T = T_o,\; 0\le x\le L,\; t=0 \qquad \textit{Initial Conditions} \tag{4}$$

$$\frac{\partial T}{\partial x} = 0,\; x=0,\; 0\le t\le x \qquad \textit{Boundary Conditions } 1 \tag{5}$$

$$\frac{\partial T}{\partial x} = 0,\; x=L,\; 0\le t\le x \qquad \textit{Boundary Conditions } 2 \tag{6}$$

Solution of mathematical model (Reneau and O'Young, 1976, 1977, 1978)

An analytical solution to equation set (3) was not considered feasible due to the variable nature of q, Cp and K, so explicit differencing methods of numerical analysis were employed to solve the equations. Several investigators working with linear systems have found that the Crank- Nicholson six point implicit differencing method provided an excellent numerical solution (Crank and Nicholson, 1947). For the solution of equation set (3) of the mathematical model, it was decided to apply the Crank-Nicholson method to the second order partial derivatives and corresponding explicit methods to the first order partials.

The grid work in Figure A-1 is a representative of the differenced system from $x = 0$ to $x = L$ (j's) and $t = 0$ to $t = \tau$ (i's).

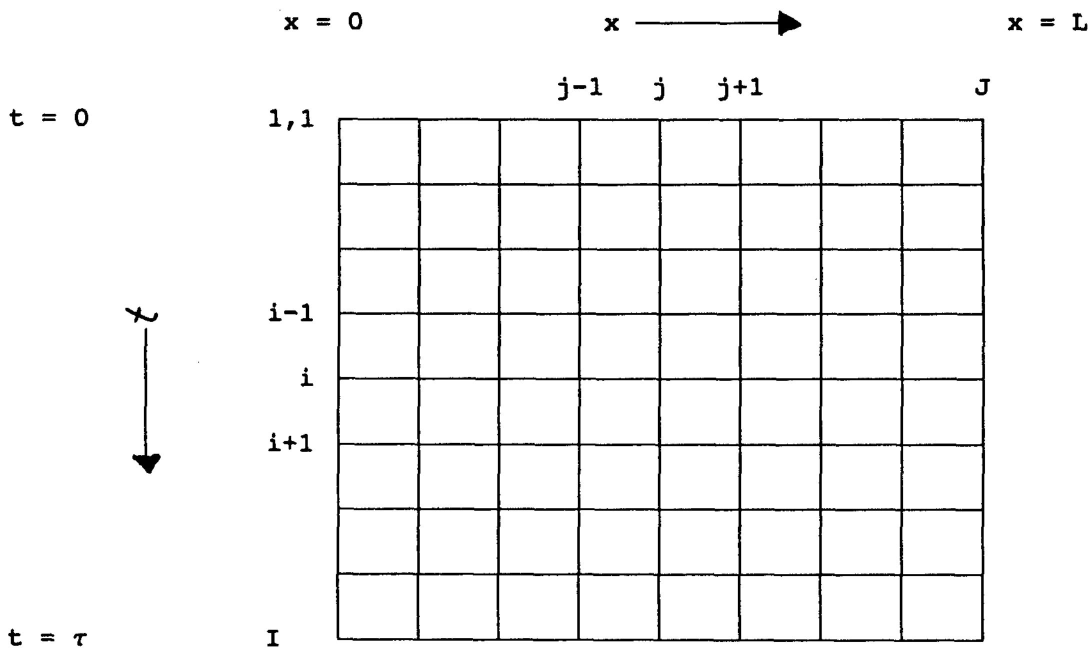

Figure A-1. Gridwork for numerical analysis

The Crank-Nicholson technique involves averaging the value of the dependent variable over the i and i + 1 row at a constant j position. The second order derivative is then evaluated at the (j, i + 1/2) position. A forward difference formulation is applied to the term to match the same position.

The above described implicit differencing method is noted for the characteristics of stability and convergence. Correct increment sizes yield reliable convergence. The model was implemented in FORTRAN IV using solution techniques of Thomas as described by Bruce et al. (1953).

This initial model was revised to allow energy flux across the surface, x = 0, during heating, convective heat loss at the skin surface during cooling and heat transfer into deep tissues including conduction into fat, convective cooling via the blood, tissue water boiling, a temperature gradient from surface to fat and a gradient of thermal properties based on measured tissue water. The model, BURNSIM, is a run interactively with the following variables changeable for each run:

Table A-1
Model parameters changeable interactively

INPUTS

TEMPIO	=	Initial surface temperature, °C; nominally 32.5 °C for man
DENS	=	Density of skin, 1.0 gm/cm^3
Q1	=	Incident heat flux either constant or as a file of fluxes, cal/cm^2-sec
BL	=	Skin thickness, 2200μm (The last 200μm is considered to be fat)
AK	=	Calculation interval, nominally .01 sec. For short exposures, the calculation interval must be at least one hundred times less than the exposure duration.
JINC	=	Number of nodes, nominally 12
TEMPB	=	Differences between TEMPIO and backwall (fat/core) temperature, °C. Note: TEMPIO + TEMPB = core temperature
Absorb	=	Absorptivity usually 0.613 assuming 10 percent convective, 90 percent radiative heating, and 5 percent of radiation intercepted by hair
Boil	=	Temperature when water boiling occurs, 100.15 °C
ETIME	=	Exposure time, seconds
ITIME	=	Maximum calculation time, usually 80-100 seconds
Nxtra	=	Number of extra nodes between the surface and node #2 at 200μm, initially set at seven, used for superficial burns Note: The seventh node must be at 175μm for an accurate time to pain prediction.
Blood	=	Factor to adjust amount of convective cooling by blood usually set at 0.001

DE1 & DE2 = $\Delta E/R$ from Arrehenius relationship for tissue temperatures from 44℃ to 50℃, or over 50℃, respectively

PL1, PLN1, or PL2 and PLN2 => log P = logN + ylog10 = PL + PLN for tissue temperatures from 44°C to 50°C, or over 50°C, respectively

Damage Rate Constants: PL1, PLN1, PL2, PLN2, DE1, DE2 (for Nodes 2-12) APL1, APLN1, APL2, APLN2, ADE1, ADE2 (for Nodes 1 and Xtra Nodes)

Cp(J) = Heat capacity as a function of depth, (J)

BK(J) = Thermal conductivity as a function of depth, (J)

PCWATER = Percent water at a skin depth of 10μm at 60 percent relative humidity

WATER(J) = Percent water at each node based on 60 percent relative humidity

OUTPUTS

Flux (I) - tabulated heat flux as a function of time

DAMAGE, W, at each depth (Node)

Maximum temperature

Threshold depth in μm (microns)

Final time - total calculation time

Time to pain

File of calculated temperatures for later plotting by HARVARD GRAPHICS

File summarizing simulation

File of temperature as printed each second on the terminal

From the relationship for first order kinetics assumed to apply in damaging tissue protein we have:

$$damage\ rate=\frac{d\Omega}{dt}=Pe^{-\Delta E/RT};$$

$$\text{total damage} = \int_{0}^{\text{ETIME}} d\Omega/dt + \int_{\text{ETIME}}^{\text{ITIME}} d\Omega/dt \tag{8}$$

if $P = N \times 10^y$ and $\Delta E/R = DE$

then:

$$\ln\frac{dw}{dt} = \ln N + y\ln 10 - \frac{\Delta E}{R}\cdot\frac{1}{T} = PL + PLN - DE\cdot\frac{1}{(T+273)} \tag{9}$$

Thus for damage calculations the following constants are entered:

PL_1 (44°C - 50°C) = 1.46

PL_2 (50°C - 100°C) = 2.24

PLN_1 (44°C - 50°C) = 147.37

PLN_2 (50°C - 100°C) = 239.47

DE_1 (44°C - 50°C) = 50,000

DE_2 (50°C - 100°C) = 80,000

The program outputs $d\Omega/dt$, for each node at each time step, total is damage for each node and a threshold depth, where $\Omega = 1$. This depth, found using inverse interpolation on two or three Ωs nearest 1 using either y or log(y).

Since the first presentations (Knox, Wachtel, and Knapp, 1978a, 1978c) BURNSIM has under gone further development.

Thermal properties of skin

Measurements of the water content of pig skin as a function of thickness were made on split thickness skin samples from several pigs.

Give a table of measured values of water content as a function of skin thickness, a least-square cubic polynomial was fit to the data and water content as a function of depth was computed from the formula:

$$W(T-d) = \frac{T}{d}(W_T - W_{T-d}) + W_{T-d} \tag{10}$$

where T is the total thickness of a slab, W_T is the fraction of water computed from the cubic equation, d is the thickness of a thin slab at a depth T-d, and W_{T-d} is the fraction of water above the thin slab.

Thermal properties of the tissue were computed from the equations (Cooper and Trezek, 1971):

$$1)\ \textit{density}:\ \gamma = \left[\frac{W_w}{\gamma_w} + \frac{W_f}{\gamma_f} + \frac{W_p}{\gamma_p}\right]^{-1} \tag{11}$$

$$2)\ \textit{heat capacity}:\ Cp = W_w Cp_w + W_f Cp_f + W_p Cp_p \qquad (12)$$

$$3)\ \textit{thermal conductivity}:\ K = \gamma \left[\frac{k_w W_w}{\gamma_w} + \frac{k_f W_f}{\gamma_f} + \frac{k_p W_p}{\gamma_p} \right] \qquad (13)$$

where the subscripts w, f, and p refer to water, fat, and protein, respectively. W_n is the mass fraction, γ_n the density, Cp_n the heat capacity, and k_n the thermal conductivity of the respective components. Values of the various terms used were:

γ_w = 1 gm/cm³	Cp_w = 1 cal/gm-°C	$k_w = 1.5X10^{-3}$ cal/cm-sec-°C
γ_f = 0.815 gm/cm³	Cp_f = 0.55 cal/gm-°C	$k_f = 4.5X10^{-4}$ cal/cm-sec-°C
γ_p = 1.54 gm/cm³	Cp_p = 0.26 cal/gm-°C	$k_p = 4.3X10^{-4}$ cal/cm-sec-°C

Fat and protein were assumed to be present in equal amounts so that:

$$W_f = W_p = (1-W_w)/2, \qquad (14)$$

and the resultant equations were:

$$\gamma = (6.18277X10^{-2}\ W_w + .938172)^{-1} \qquad (15)$$

$$K = \gamma(1.08432X10^{-3}\ W_w + 4.15684X10^{-4}) \qquad (16)$$

$$Cp = .595\ W_w + .405 \qquad (17)$$

Using the equations above, the profile of thermal properties was calculated for skin depths of from 80 to 2000μm. A linear extrapolation of tissue water content from a depth of 80μm to the skin surface was made using a stratum corneum water content calculated from Rushmer et al. (1966) and the ambient percent humidity during the experimental phase of the project. This calculated water profile was used to complete the calculation of thermal properties profile from 80μm to the skin surface. The thermal properties of the skin at 2200μm were assumed to be those of fat. These new thermal properties replaced those chosen by Morse et al. (1973) and used during previously reported simulations (Knox, Wachtel, and Knapp, 1978a, 1978c). See the paper entitled "Thermal properties calculated from measured water content as a function of depth in porcine skin" (Knox et al., 1986).

Intraskin temperatures

In earlier simulations (Knox et al, 1978a, 1978c) it became apparent that unless the temperature calculations reasonably represented what actually occurred in the skin, adjustment of the values for PL, PLN and DE in the damage equation to match a few data points would not be likely to result in a model which works well for all cases. Fortunately

11 intraskin temperature profiles were recorded on FM magnetic tape. These voltage records were digitized and converted to tables of temperatures at 100 samples per second. Figure A-2 presents the one page summary report from a simulation of the exposure of Pig 294RF to a 3.47 cal /cm^2-sec fire for 3.02 seconds. Note that boiling occurred (confirmed by blister formation, Figure A-3) and that the surface reached a maximum of 128.724°C. Predicted threshold depth was 1520μm. Three observed temperature profiles are overlayed on the calculated temperature profiles (for nodal depths of 0, 200, 400....2200μm) in Figures A-4, A-5, and A-6. The oscillations in the observed temperature profile are most probably due to a "hunting" in the autoregulation of tissue perfusion by blood. The frequency, for example, is similar to that seen in studies of microcirculation.

MODEL NAME OR DESCRIPTION: PIG 294RF ABS 0.613

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPIO=	34.9700	DENS=	1.00000	Q1=	3.47000
BL=	.220000	AK=	.100000E-01	JINC=	12
TEMPB=	3.3600	ABSORB=	.613000	BOIL=	100.150
APL1=	.780000	APLN1=	285.520	ADE1=	93534.9
APL2=	.600000	APLN2=	117.430	ADE2=	39109.8
PL1=	1.46	PLN1=	147.37	DE1=	50000.00
PL2=	2.24	PLN2=	239.47	DE2=	80000.00
ETIME=	3.02	ITIME=	80.00	NXTRA=	8
BLOOD=	.0010				

EXTRA NODES: 22.2 44.4 66.7 88.9 111.1 133.3 155.6 177.8

FLUX FILE I.D.: .00 2

FLUX(I)=
1 3.470 2 3.470

W= .39950E+01
W= .40733E+00
W= .45290E-01

D= .72442E+01
D= .73778E+01
D= .74955E+01

W =	.19755E+19	AT DEPTH (IN MICRONS)=	.112535E-06
W =	.82482E+12	AT DEPTH (IN MICRONS)=	200.000
W =	.26532E+09	AT DEPTH (IN MICRONS)=	400.000
W =	.57713E+06	AT DEPTH (IN MICRONS)=	600.000
W =	.84775E+04	AT DEPTH (IN MICRONS)=	800.000
W =	.44473E+03	AT DEPTH (IN MICRONS)=	1000.00
W =	.39319E+02	AT DEPTH (IN MICRONS)=	1200.00
W =	.39950E+01	AT DEPTH (IN MICRONS)=	1400.00
W =	.40733E+00	AT DEPTH (IN MICRONS)=	1600.00
W =	.45290E-01	AT DEPTH (IN MICRONS)=	1800.00
W =	.89902E-02	AT DEPTH (IN MICRONS)=	2000.00
W =	.00000E+00	AT DEPTH (IN MICRONS)=	2200.00

MAXIMUM TEMPERATURE = 128.724

THRESHOLD DEPTH = 1528.

FINAL TIME = 80.00

Figure A-2. Summary report for simulation of Pig 294RF to a 3.47 cal/cm²-sec fire for 3.02 seconds.

Figure A-3. Intraskin thermocouple (0.003", "located superficially") shown prior to burn (left) and subsequent to exposure to 3.47 cal•cm^{-2}•sec^{-1} for 3.02 seconds (right).

Gross grade = 13 New micro grade = 8
Threshold depth = 1465μm

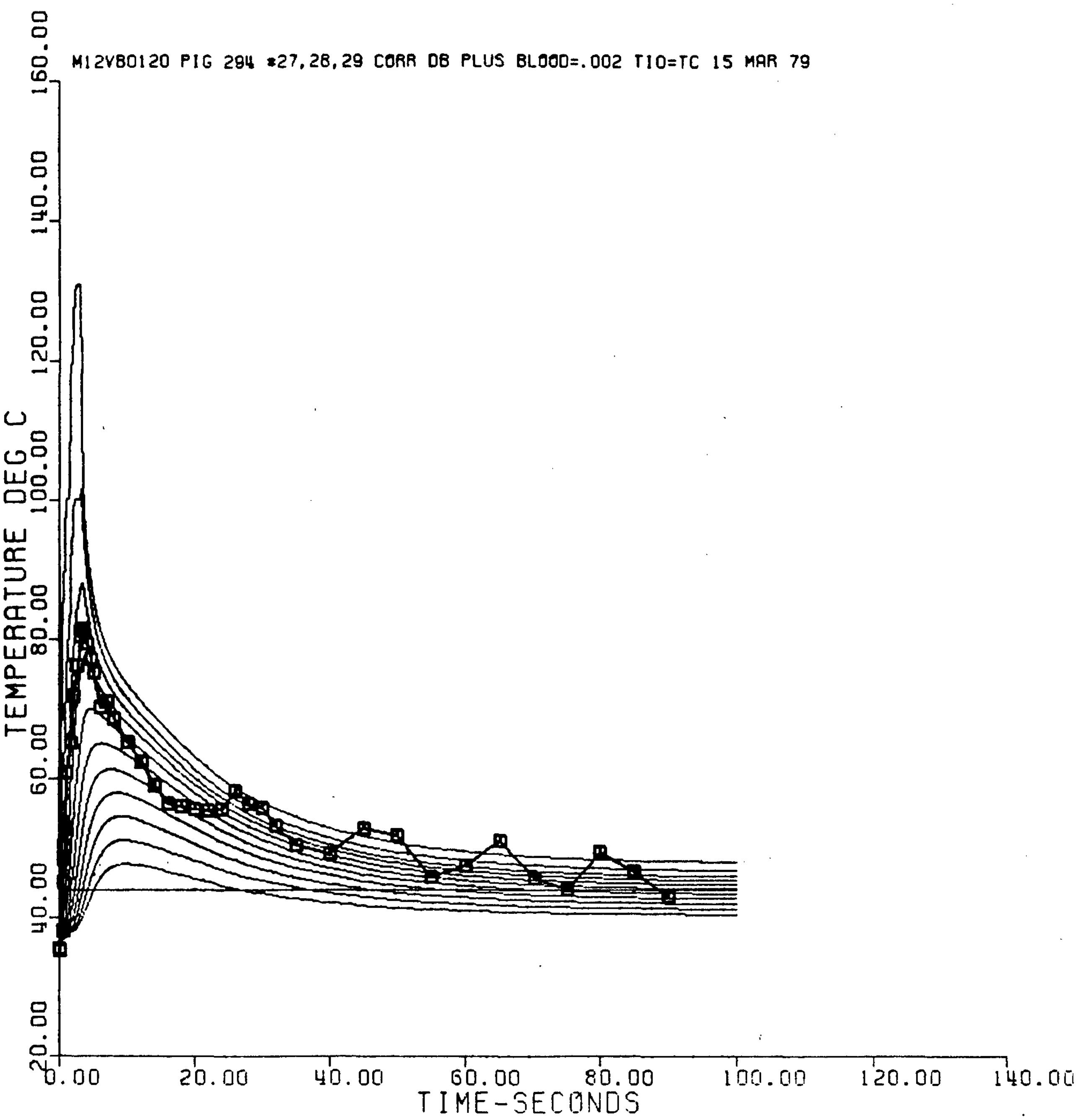

Figure A-4. Predicted skin temperature at each node (solid lines) and measured intraskin temperature in pig 284 location #27 when exposed to 3.47 cal.cm^{-2}.sec^{-1} for 3.02 seconds

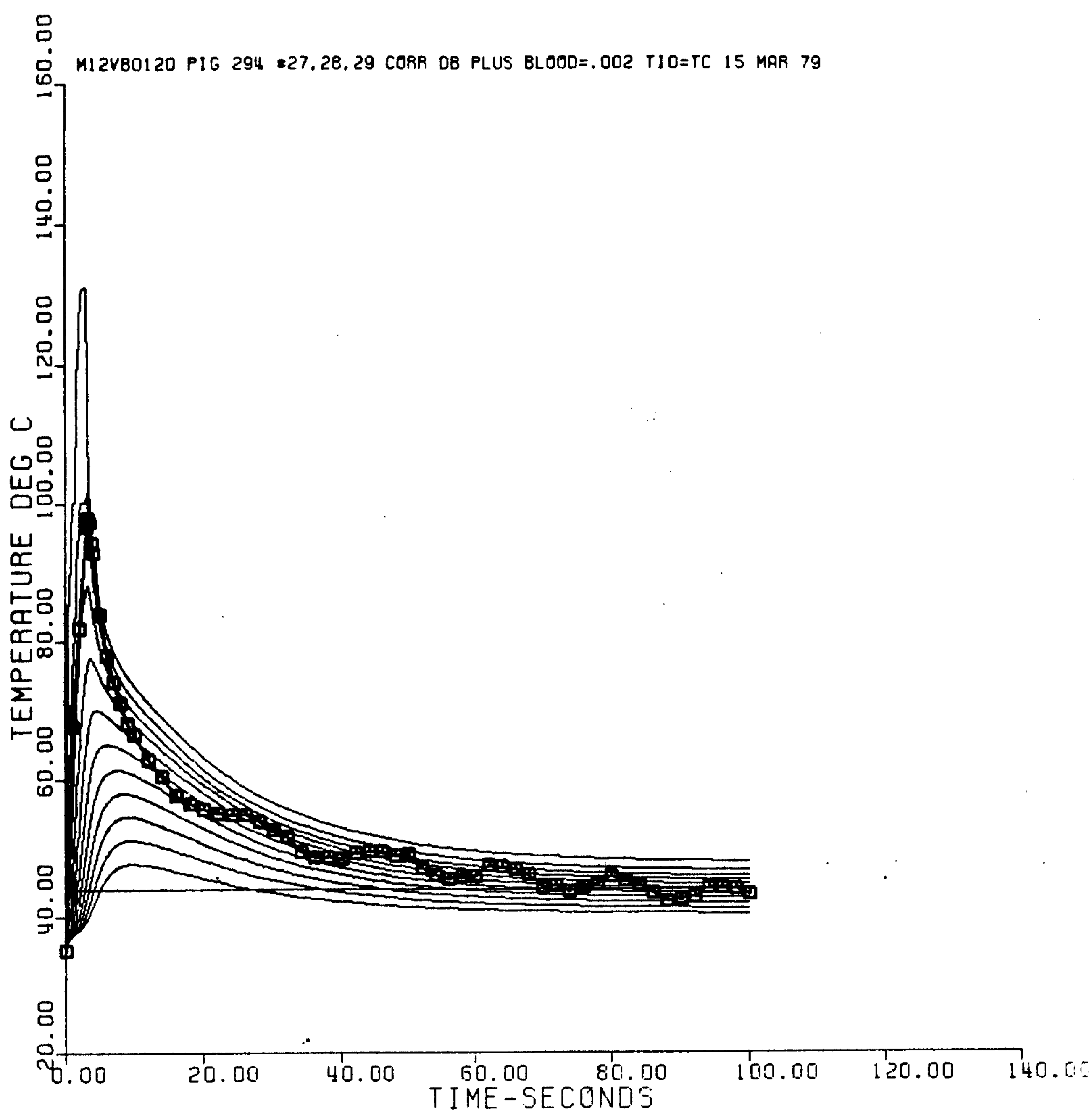

Figure A-5. Predicated skin temperature at each node (solid lines) and measured intraskin temperature in pig 284 location #28 when exposed to 3.47 $cal \cdot cm^{-2} \cdot sec^{-1}$ for 3.02 seconds

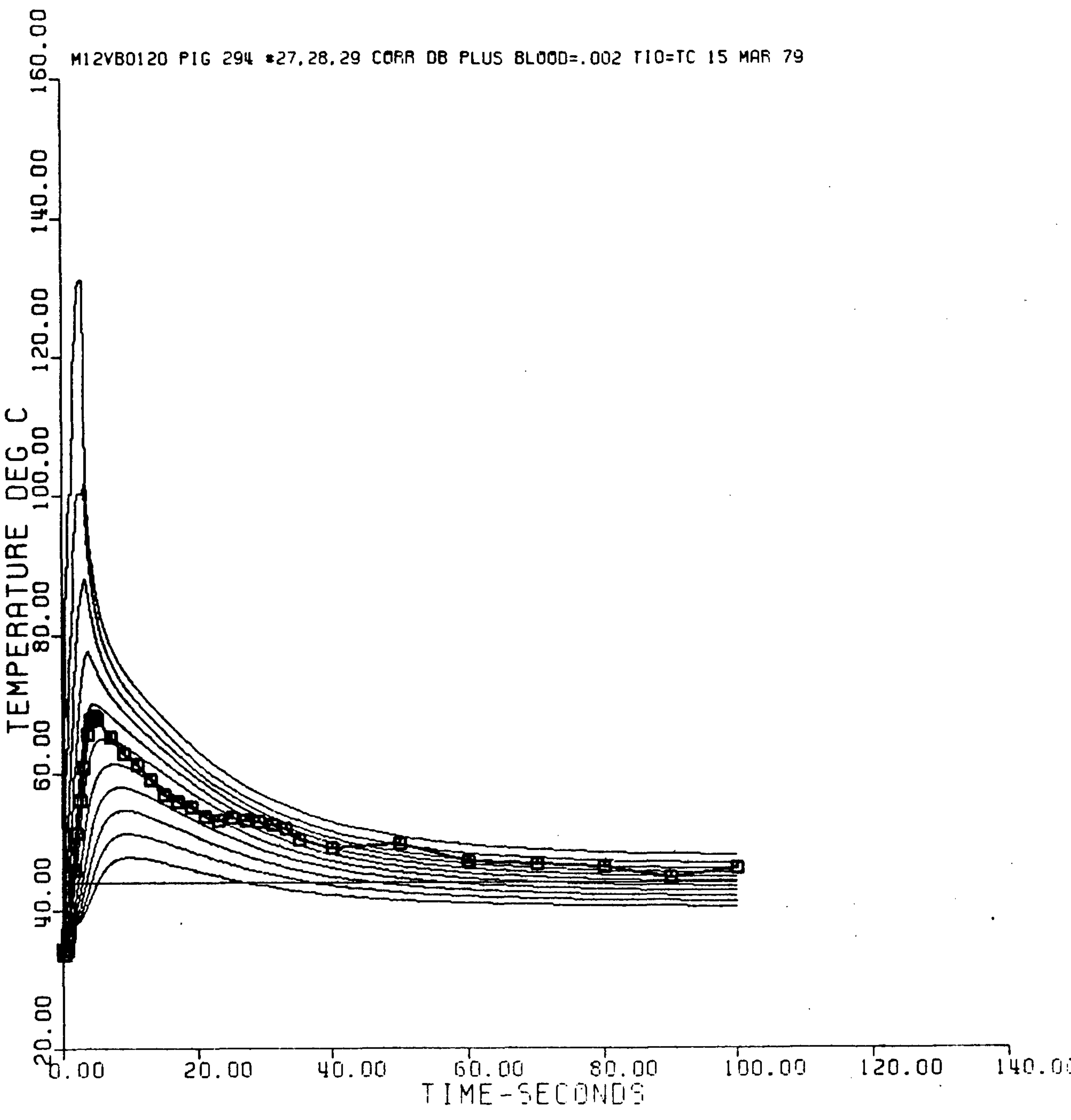

Figure A-6. Predicated skin temperature at each node (solid lines) and measured intraskin temperature in pig 284 location #29 when exposed to 3.47 cal$\cdot$cm$^{-2}\cdot$sec^{-1} for 3.02 seconds

APPENDIX B

```
C       Last Edited March 5, 1992
C       ****************** 12-POINT BURN PREDICTION MODEL***************

C     PROGRAM BURNSIM        ! BURN PREDICTION MODEL WITH WATER BOILING
C                            ! AND USE OF EITHER CONSTANT OR TABULATED FLUX
C                            ! AND VARIABLE COOLING BY BLOOD FROM NODES 2
C                            ! AND 3 BEGINNING AT .01 SEC AND LINEARLY
C                            ! INCREASING TO 20 SEC AND THEN REMAINING
C                            ! CONSTANT......

C                            ! CHANGED TO DO INTEGRATION OF DAMAGE W & XW
C                            ! WITHIN PROGRAM AND NOT OUT TO DISK AND BACK

C                            ! CHANGED TO INCORPORATE THE CHANGES IN MODEL
C                            ! 7 NAMELY DIFFERENT RATE CONSTANTS ETC FOR
C                            ! SUPERFICIAL NODES AND VARIABLE AK IN BLUD

C       THIS MODEL WAS DEVELOPED UNDER CONTRACT FOR THE U.S. ARMY
C       MEDICAL RESEARCH AND DEVELOPMENT COMMAND, AND THE U.S. ARMY
C       AEROMEDICAL RESEARCH LABORATORY, FORT RUCKER AL. 36362,
C       STANLEY C. KNAPP, COL, MC, COMMANDING, BY FRANCIS S. KNOX, III,
C       PH.D. WITH THE ASSISTANCE OF DANIEL D. RENEAU, PH.D., NELSON
C       O'YOUNG, AND CHET ELLIS, M.S.

C       ADDITIONAL DEVELOPMENT CONDUCTED UNDER ILIR FUNDING AT USAARL
C       AND ON OWN TIME BY FRANCIS S. KNOX, III, PH.D.

C       QUESTIONS AND COMMENTS SHOULD BE ADDRESSED TO:

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C      This copy current working copy of Dr. Knox. Other copies
C      are not to be further distributed without permission from
C      Dr. Knox.
C.....
      INCLUDE 'FGRAPH.FI'
      INCLUDE 'FGRAPH.FD'
      REAL*4 ITIME,NOFIL,TP,SUM(13),DW(13)
      INTEGER CHANGE,PTS,AGAIN,PROCED
      INTEGER*4 DUMMY4
      INTEGER*2 DUMMY2
      DIMENSION T(12),F(12),G(12),H(12),W(12),Z(12),SV(12),U(12)
      DIMENSION CP(12,2),BK(12,2),D(12),DSCRPT(20)
      DIMENSION ID(4),FLUX(600),Q(12)
```

```
      DIMENSION XTIME(12),ZTIME(12),IFLAG(12),JFLAG(12)
      DIMENSION WATER(12,2),ROCON(2),THCON(2),CPCON(2)
      DIMENSION XW(8),XTRA(8),XTRALG(8),XTMP(8),XDW(8),XSUM(8)
      CHARACTER RESP*1,FILNAM*8,SUMFILE*8,PROFILE*8,TFILE*8
      EQUIVALENCE (NOFIL,IBLNK)
        DATA NOFIL/'    '/
        DATA MAXDIM/12/,D2/200./
        DATA THCON/1.084316E-3,4.1568401E-4/
        DATA ROCON/6.1827743E-2,0.93817226/
        DATA CPCON/0.595,0.405/

C       LOGICAL UNIT 1 INPUT  : 'REN12.DAT'; INITIAL VALUES OF PARAMETERS
C       LOGICAL UNIT 1 SCRATCH:  VALUES OF XW (IF COMPUTED)
C       LOGICAL UNIT 2 SCRATCH:  VALUES OF W (COMPUTED)
C       LOGICAL UNIT 3 OUTPUT :  PROFILE; TEMPERATURE PROFILES
C       LOGICAL UNIT 4 INPUT  :  FILNAM; NAME OF FLUX FILE
C       LOGICAL UNIT 4 OUTPUT :  TFILE; DATA FOR PLOTTING TEMPERATURE
C                                PROFILES
C       LOGICAL UNIT 7 OUTPUT :  SUMMARY PRINTOUT

C*******Introduction to BURNSIM
        CALL COLORS
        DUMMY4=SETBKCOLOR( $BLUE )
        CALL WELCOME(PROFILE)
C*******Read REN12.DAT input file
        CALL READDATA(TEMPIO,DENS,Q0,BL,AK,BOIL,ABSORB,JINC,TEMPB,
     +  ITIME,ETIME,PCWATR,BLOOD,CP,BK,PL2,PLN2,PL1,PLN1,DE2,DE1,
     +  APL1,APLN1,APL2,APLN2,ADE1,ADE2,WATER)
        OPEN(UNIT=1,FORM='UNFORMATTED',STATUS='SCRATCH')
        OPEN(UNIT=2,FORM='UNFORMATTED',STATUS='SCRATCH')
        OPEN(UNIT=3,FILE=PROFILE,FORM='FORMATTED',STATUS='UNKNOWN')
        FLUX(1) = Q0
        FLUX(2) = Q0
        NFLX = 2
        FILNAM = NOFIL
        PPL1 = PL1
        PPLN1 = PLN1
        DDE1 = DE1
        APPL1 = APL1
        APPLN1 = APLN1
        ADDE1 = ADE1
        NXTRA = 0
        NXTRA0 = NXTRA
C*******Display input values on screen
        CALL SHOWVALUE(TEMPIO,DENS,FLUX,BL,AK,JINC,TEMPB,
     + ABSORB,BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,
     + BLOOD,APL1,APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
        DO WHILE (AGAIN .EQ. 0)
         CALL PROCEED(RESP,PROCED,AGAIN)
         IF(PROCED.EQ.0) THEN
          PTS=1
          TIME=0.
```

```
          CHANGE=0
          MN=0
          CALL clearscreen( $GCLEARSCREEN )
          WRITE(*,10)
10     FORMAT(//,15X,'TYPE THE NUMBER OF THE FUNCTION BELOW THAT YOU',/
     + ,15X,'WISH TO PERFORM.',////,20X,'CHOOSE A FUNCTION NUMBER: ',/,
     + 25X,'1 - CHANGE SELECTED INITIAL VALUES',/,25X,'2 - NO CHANGES',
     + '--CONTINUE RUNNING THE PROGRAM',/,25X,'3 - EXIT',//,20X,'PLEASE'
     + ' ENTER THE FUNCTION NUMBER: '$)
          READ(*,20)IANSR
20     FORMAT(I2)
          CALL clearscreen( $GCLEARSCREEN )
          IF(IANSR.EQ.1) THEN
           DOWHILE(CHANGE.EQ.0)
            CALL SHOWVALUE(TEMPIO,DENS,FLUX,BL,AK,JINC,TEMPB,
     + ABSORB,BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,
     + BLOOD,APL1,APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
            WRITE(*,30)
30     FORMAT(///,15X,'DO YOU WANT TO MAKE ANY CHANGES? TYPE Y/N '$)
            READ(*,40)RESP
40     FORMAT(A1)
            IF(RESP.EQ.'Y'.OR.RESP.EQ.'y') THEN
             CALL CLEARSCREEN( $GCLEARSCREEN )
             WRITE(*,50)
50     FORMAT(/T5,'PICK A NUMBER',//T10,'1=TEMPIO',T30,'8=ETIME',//
     + T10,'2=DENS',T30,'9=PL1',/T10,'3=Q1',T30,'10=PLN1',//
     + T10,'4=BL',T30,'11=PL2',/T10,'5=AK',T30,'12=PLN2',//
     + T10,'6=JINC',T30,'13=DE1',/T10,'7=TEMPB',T30,'14=DE2',//
     + T10,'15=ITIME',T30,'16=ABSORBTIVITY'//
     + T10,'17=BOIL',T30,'18=EXTRA NODES'//
     + T10,'19=BLOOD',T30,'20=APL1'//
     + T10,'21=APLN1',T30,'22=APL2'//
     + T10,'23=APLN2',T30,'24=ADE1',T55,'25=ADE2',/,9X,$)
             READ(*,20)INUM
             IF(INUM.EQ.1) THEN
              WRITE(*,60)TEMPIO
60     FORMAT(//,9X,'THE VALUE FOR TEMPIO IS: ',F10.5,' INPUT NEW VALU'
     + 'E: '$)
              READ(*,70)TEMPIO
70    FORMAT(G10.5)
             ELSEIF(INUM.EQ.2) THEN
              WRITE(*,80)DENS
80     FORMAT(//,9X,'THE VALUE FOR DENS IS: ',F10.5,' INPUT NEW VALUE: '
     + $)
              READ(*,70)DENS
             ELSEIF(INUM.EQ.3) THEN
              WRITE(*,90)
90     FORMAT(//,9X,'ENTER THE FLUX FILE NAME (TYPE A <CR> IF NO FILE '
     + ,/,9X,'IS TO BE USED): '$)
              READ(*,100)FILNAM
100    FORMAT(A8)
C*******Read in flux file
```

```
            IF (FILNAM.NE.NOFIL) THEN
             WRITE(*,110)
110   FORMAT(/,9X,'ENTER FLUX ID (UP TO 8 CHARACTERS): '$)
             READ(*,120)
120   FORMAT(4A2)
             WRITE(*,130)
130   FORMAT(/,9X,'ENTER THE NUMBER OF POINTS IN FLUX FILE:  '$)
             READ(*,*) NFLX
              DO WHILE (NFLX .GT. 600)
               WRITE(*,140)
140   FORMAT(/,9X,'THE FLUX FILE MUST CONTAIN NO MORE THAN 600 DATA'
     +  ,/,9X,'POINTS.  REENTER A NUMBER LESS THAN OR EQUAL TO 600. '$)
               READ(*,*) NFLX
              END DO
              WRITE(*,150)
150   FORMAT(/,9X,'ENTER THE SAMPLE INTERVAL IN SECONDS: '$)
              READ(*,*)TDELT
              OPEN(UNIT=4,FILE=FILNAM,FORM='FORMATTED',STATUS=
     + 'OLD')
              READ(4,*) (FLUX(I),I=1,NFLX)
              CLOSE (4)
               IF(NFLX.LE.0) STOP 'ERROR----TOO FEW FLUX POINTS.'
              WRITE(*,430)ID,TDELT,NFLX
             ELSE
              WRITE(*,160)FLUX(1)
160   FORMAT(//,9X,'CONSTANT Q-VALUE = ',F10.5,'  INPUT NEW VALUE: '
     + $)
              READ(*,70)FLUX(1)
              FLUX(2)=FLUX(1)
              NFLX = 2
              DO I=1,4
               ID(I) = IBLNK
              END DO
             END IF
           ELSEIF(INUM.EQ.4) THEN
            WRITE(*,170)BL
170   FORMAT(//,9X,'THE VALUE FOR BL IS: ',F10.5,'  INPUT NEW VALUE: '
     + $)
            READ(*,70)BL
           ELSEIF(INUM.EQ.5) THEN
            WRITE(*,180)AK
180   FORMAT(//,9X,'THE VALUE FOR AK IS: ',F10.5,'  INPUT NEW VALUE: '
     + $)
            READ(*,70)AK
           ELSEIF(INUM.EQ.6) THEN
            WRITE(*,190)JINC
190   FORMAT(//,9X,'THE VALUE FOR JINC IS: ',I30,'  INPUT NEW VALUE: '
     + $)
            READ(*,20)JINC
            IF (JINC.GT.MAXDIM) JINC=MAXDIM
           ELSEIF(INUM.EQ.7) THEN
          WRITE(*,200)TEMPB
```

```
200    FORMAT (//,9X,'THE VALUE FOR TEMPB IS: ',F10.5,'  INPUT NEW VA'
     + 'LUE: '$)
             READ(*,70)TEMPB
           ELSEIF(INUM.EQ.8) THEN
             WRITE(*,210)ETIME
210    FORMAT(//,9X,'THE VALUE FOR ETIME IS: ',F10.5,'  INPUT NEW VALU'
     + 'E: '$)
             READ(*,70)ETIME
           ELSEIF(INUM.EQ.9) THEN
             WRITE(*,220)PL1
220    FORMAT(//,9X,'THE VALUE FOR PL1 IS: ',F10.5,'  INPUT NEW VALUE'
     + ': '$)
             READ(*,70)PL1
             PPL1=PL1
           ELSEIF(INUM.EQ.10) THEN
             WRITE(*,230)PLN1
230    FORMAT(//,9X,'THE VALUE FOR PLN1 IS: ',F10.5,'  INPUT NEW VALU'
     + 'E: '$)
             READ(*,70)PLN1
             PPLN1=PLN1
           ELSEIF(INUM.EQ.11) THEN
             WRITE(*,240)PL2
240    FORMAT(//,9X,'THE VALUE FOR PL2 IS: ',F10.5,'  INPUT NEW VALUE'
     + ': '$)
             READ(*,70)PL2
           ELSEIF(INUM.EQ.12) THEN
             WRITE(*,250)PLN2
250    FORMAT(//,9X,'THE VALUE FOR PLN2 IS: ',F10.5,'  INPUT NEW VALUE'
     + ': '$)
             READ(*,70)PLN2
           ELSEIF(INUM.EQ.13) THEN
             WRITE(*,260)DE1
260    FORMAT(//,9X,'THE VALUE FOR DE1 IS: ',F10.1,'  INPUT NEW VALUE'
     + ': '$)
             READ(*,70)DE1
             DDE1=DE1
           ELSEIF(INUM.EQ.14) THEN
             WRITE(*,270)DE2
270    FORMAT(//,9X,'THE VALUE FOR DE2 IS: ',F10.1,'  INPUT NEW VALUE'
     + ': '$)
             READ(*,70)DE2
           ELSEIF(INUM.EQ.15) THEN
             WRITE(*,280)ITIME
280    FORMAT(//,9X,'THE VALUE FOR ITIME IS: ',F10.5,'  INPUT NEW VALU'
     + 'E: '$)
             READ(*,70)ITIME
           ELSEIF(INUM.EQ.16) THEN
             WRITE(*,290)ABSORB
290    FORMAT(//,9X,'THE VALUE FOR ABSORB IS: ',F10.5,'  INPUT NEW VAL'
     + 'UE: '$)
             READ(*,70)ABSORB
           ELSEIF(INUM.EQ.17) THEN
```

```
            WRITE(*,300)BOIL
300     FORMAT(//,9X,'THE VALUE FOR BOIL IS: ',F10.5,'  INPUT NEW VALUE'
     + ': '$)
            READ(*,70)BOIL
           ELSEIF(INUM.EQ.18) THEN
            NXTRA0 = NXTRA
            WRITE(*,310)NXTRA
310     FORMAT(//,9X,'THE NUMBER OF EXTRA NODES IS: ',I4,'  INPUT NEW'
     + ' VALUE: '$)
            READ(*,20)NXTRA
            IF (NXTRA.NE.0) THEN
             IF (NXTRA.GT.8) NXTRA=8
             IF (NXTRA0.NE.0) WRITE(*,320) (XTRA(I),I=1,NXTRA0)
320     FORMAT(/,9X,'CURRENT EXTRA NODES: ',8F6.1)
             WRITE(*,330)
330     FORMAT(//,9X,'ENTER NEW VALUES SEPARATED BY COMMAS, OR A <CR> '
     +  ,/,9X,'IF THE PROGRAM IS TO CALCULATE VALUES. '$)
             READ(*,340)XTRA
340     FORMAT(8G6.1)
             IF (XTRA(1).LE.0) THEN
C*******Numerator in next statement is specific for n-point model
              DXTRA = D2/(NXTRA+1)
              DO I=1,NXTRA
               XTRA(I)   = DXTRA*I
              END DO
             END IF
             DO I=1,NXTRA
              XTRALG(I) = ALOG(XTRA(I))
             END DO
            END IF
            NXTRA0 = NXTRA
           ELSEIF(INUM.EQ.19) THEN
            WRITE(*,350)BLOOD
350     FORMAT(//,9X,'THE VALUE FOR BLOOD IS: ',F10.5,'  INPUT NEW VALU'
     + 'E: '$)
            READ(*,70)BLOOD
           ELSEIF(INUM.EQ.20) THEN
            WRITE(*,360)APL1
360     FORMAT(//,9X,'THE VALUE FOR APL1 IS: ',F10.5,'  INPUT NEW VALUE'
     + ': '$)
            READ(*,70)APL1
           ELSEIF(INUM.EQ.21) THEN
            WRITE(*,370)APLN1
370     FORMAT(//,9X,'THE VALUE FOR APLN1 IS: ',F10.5,'  INPUT NEW VALU'
     + 'E: '$)
            READ(*,70)APLN1
           ELSEIF(INUM.EQ.22) THEN
            WRITE(*,380)APL2
380     FORMAT(//,9X,'THE VALUE FOR APL2 IS: ',F10.5,'  INPUT NEW VALUE'
     + ': '$)
            READ(*,70)APL2
           ELSEIF(INUM.EQ.23) THEN
```

```
              WRITE(*,390)APLN2
390       FORMAT(//,9X,'THE VALUE FOR APLN2 IS: ',F10.5,'  INPUT NEW VALU'
     + 'E: '$)
              READ(*,70)APLN2
             ELSEIF(INUM.EQ.24) THEN
              WRITE(*,400)ADE1
400       FORMAT(//,9X,'THE VALUE FOR ADE1 IS: ',F10.1,'  INPUT NEW VALUE'
     + ': '$)
              READ(*,70)ADE1
             ELSEIF(INUM.EQ.25) THEN
              WRITE(*,410)ADE2
410       FORMAT(//,9X,'THE VALUE FOR ADE2 IS: ',F10.1,'  INPUT NEW VALUE'
     + ': '$)
              READ(*,70)ADE2
             ELSE
              CHANGE=1
             ENDIF
            ELSE
             CHANGE=1
            END IF
           END DO
           REWIND 1
          ELSEIF(IANSR.EQ.2) THEN
           CALL CLEARSCREEN( $GCLEARSCREEN )
           CALL DESCRIPT(DSCRPT,SUMFILE,TFILE)
           TP=999.
           AJ=JINC
           Q1 = FLUX(1)
           H1=BL/(AJ-1.0)
C*******Initialize depth nodes D(J)
           D(1) = -16.
           DO I=2,JINC
            D(I) = H1*(I-1)*1.E4
            D(I) = ALOG(D(I))
           END DO
            DTJ = TEMPB/(JINC-1)
            DO J=1,JINC
             WATER(J,1) = WATER(J,2)
             CP(J,1) = CP(J,2)
             BK(J,1) = BK(J,2)
             XTIME(J) =0.
             ZTIME(J) =0.
             IFLAG(J) =0.
             JFLAG(J) =0.
             T(J) = DTJ*(J-1)+TEMPIO
            END DO
             WRITE(4,420)TIME,T(1),T(2),T(3),T(4),T(5),T(6),T(7),T(8)
     + ,T(9),T(10),T(11),T(12)
420       FORMAT(13(F9.5,2X))
             K=1
             CALL SHOWVALUE(TEMPIO,DENS,FLUX,BL,AK,JINC,TEMPB,ABSORB,
     + BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,BLOOD,APL1,
```

```
     + APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
            WRITE(3,430)ID,TDELT,NFLX,(I,FLUX(I),I=1,NFLX)
            WRITE(7,430)ID,TDELT,NFLX,(I,FLUX(I),I=1,NFLX)
430    FORMAT(/,9X,'FLUX FILE I.D.: ',4A2,F7.2,I4://' FLUX(I)='
     + /(' ',10(I5,F8.3)))
            JJJJ=0
            F(1)=-BK(2,1)/(2.0*H1*H1)-BK(1,1)/(2.0*H1*H1)
            G(1) = (BK(1,1)+BK(2,1))/(2.0*H1*H1)+DENS*CP(1,1)/AK
            H(1)=0.0
            ITTR = 0
            IFLX = 1
            EITIM1 = ITIME+1.
            IF (FILNAM.EQ.NOFIL) TDELT=AK
            FFDG = TDELT/AK
            KFDG = FFDG+.0001
            TMPMAX = 0.
            QCONST = ABSORB*60.892
            BLUD = 0.
            M = -1
            TIME = 0.
            ITFLG = 0
            CALL SUB12(TIME,T,XTIME,JINC,BLUD,CP,BK,NXTRA,XTMP,M,EM)
            DOWHILE(TIME.LT.ITIME.AND.ITFLG.EQ.0.OR.TIME.LT.ETIME)
C*******The next program statement automatically chooses the proper
C       interval in the flux table for the computation of QT and Q1 for
C       either constant or variable flux.
C            KFDG (=FFDG) = 1 for constant flux
C                         = integer ratio of the tabular time step to
C                           to model the time step for the tabulated flux
             IF (MOD(ITTR,KFDG).EQ.0.AND.IFLX.LT.NFLX) IFLX=IFLX+1
             ITTR = ITTR+1
             P = (ITTR-KFDG*(IFLX-2))/FFDG
             QT = (1.-P)*FLUX(IFLX-1)+P*FLUX(IFLX)
             Q1 = QT*QCONST
             JJJJ = JJJJ+1
             TIME=JJJJ*AK
             IF (TIME.GE..01.AND.TIME.LE.20.) BLUD=(TIME-AK)/(20.-AK)*
     + BLOOD
             IF(TIME.GE.ETIME) Q1=-5.E-4*(T(1)-23.9)
             Z(1)=-F(1)*T(2)-((BK(1,1)+BK(2,1))/(2.0*H1*H1)-(DENS*
     +CP(1,1))/AK)*T(1)+Q1
             N=JINC-1
             DO J=2,N
              F(J)=-BK(J+1,1)/(2.0*H1*H1)
              G(J)=(BK(J,1)+BK(J+1,1))/(2.0*H1*H1)+DENS*CP(J,1)/AK
              H(J)=-BK(J,1)/(2.0*H1*H1)
              Z(J)=-F(J)*T(J+1)-((BK(J,1)+BK(J+1,1))/(2.*H1*H1)-DENS
     + *CP(J,1)/AK)*T(J)-H(J)*T(J-1)
              IF (J.LE.3) Z(J) = Z(J)-1.675*H1/BK(J,1)*BLUD*(T(J)
     + -TEMPIO+TEMPB)
             END DO
             F(JINC)=0.0
```

```
            G(JINC)=(BK(JINC,1)+BK(JINC-1,1))/(2.0*H1*H1)+DENS*
     + CP(JINC,1)/AK
            H(JINC)=-(BK(JINC,1)+BK(JINC-1,1))/(2.0*H1*H1)
            DT=T(JINC-1)-(TEMPIO+TEMPB)
            Z(JINC)=(H(JINC)+(DENS*CP(JINC,1)/AK))*T(JINC)-H(JINC)*
     + T(JINC-1)-BK(JINC,1)*DT/H1**2
            W(1)=G(1)
            U(1)=Z(1)/W(1)
            DO J=2,JINC
             JM1=J-1
             SV(JM1)=F(JM1)/W(JM1)
             W(J)=G(J)-H(J)*SV(JM1)
             U(J)=(Z(J)-H(J)*U(JM1))/W(J)
            END DO
             T(JINC)=U(JINC)
             KK=JINC-1
             DO J=1,KK
              KMJ=JINC-J
              IF (IFLAG(KMJ).NE.1) THEN
               T(KMJ)=U(KMJ)-SV(KMJ)*T(KMJ+1)
               IF (JFLAG(KMJ).NE.1) THEN
                IF(T(KMJ).GE.BOIL) THEN
                 T(KMJ) = BOIL
                 IF (KMJ.NE.1) THEN
                  Q(KMJ) = BK(KMJ,1)*(T(KMJ)-T(KMJ+1))/H1
                 ELSEIF(KMJ.EQ.1) THEN
                  Q(KMJ) = QT
                 END IF
                 XTIME(KMJ) = 539.*H1/Q(KMJ)*WATER(KMJ,1)
                 ZTIME(KMJ) = XTIME(KMJ)+TIME
                 IFLAG(KMJ) = 1
                END IF
               END IF
              ELSEIF (IFLAG(KMJ).EQ.1) THEN
               IF (TIME.GE.ZTIME(KMJ)) THEN
                WATER(KMJ,1) = PCWATR
                CP(KMJ,1)=(CPCON(1)*WATER(KMJ,1)+CPCON(2))/(ROCON(1)*
     + WATER(KMJ,1)+ROCON(2))
                BK(KMJ,1) = (THCON(1)*WATER(KMJ,1)+THCON(2))/(ROCON(1)
     + *WATER(KMJ,1)+ROCON(2))
                IFLAG(KMJ) = 0
                XTIME(KMJ) = 0.
                JFLAG(KMJ) = 1
               END IF
              ENDIF
             END DO
C*******Interpolate extra temperatures between the surface and second node
             IF (NXTRA.NE.0) THEN
              IF (T(2).EQ.T(1)) THEN
C*******For constant temperature
               DO I=1,NXTRA
                XTMP(I) = T(2)
```

```
          END DO
         ELSEIF (T(2).EQ.T(3)) THEN
C*******Linear interpolation
          DO I=1,NXTRA
           P = XTRA(I)/D2          !D(1) = 0.
           XTMP(I) = (1.-P)*T(1)+P*T(2)
          END DO
         ELSE
C*******3-point Lagrange interpolation for equally spaced abscissae
          DO I=1,NXTRA
           P = (XTRA(I)-D2)/D2          !D(1) = 0. (SURFACE)
           XTMP(I) = .5*P*(P-1.)*T(1)+(1.-P**2)*T(2)+.5*P*(P+1.)
     + *T(3)
          END DO
         END IF
        END IF
        IF (ABS(ETIME-TIME) .LE. 0.5*AK) THEN
         DO I=1,JINC
          IF (IFLAG(I).NE.0) THEN
           WATER(I,1) = (ZTIME(I)-TIME)/XTIME(I)*(WATER(I,1)-
     + PCWATR)+PCWATR
           CP(I,1) = (CPCON(1)*WATER(I,1)+CPCON(2))/(ROCON(1)*
     + WATER(I,1)+ROCON(2))
           BK(I,1) = (THCON(1)*WATER(I,1)+THCON(2))/(ROCON(1)*
     + WATER(I,1)+ROCON(2))
          END IF
         END DO
         DO I=1,JINC
          XTIME(I) = 0.
          IFLAG(I) = 0
          JFLAG(I) =1
         END DO
        ENDIF
        IF (T(1).GT.TMPMAX) TMPMAX=T(1)
        ITFLG = -1 !ITFLG SET TO 0 IF ANY TEMPERATURE .GE. 44 DEGREES
        DO J=1,JINC
         IF (T(J).LT.44.) THEN
          DW(J) = 0.
         ELSE
          ITFLG = 0
          IF(T(J).LT.50.) THEN
           PL1 = PPL1
           PLN1 = PPLN1
           DE1 = DDE1
           APL1 = APPL1
           APLN1 = APPLN1
           ADE1 = ADDE1
           DWLN=PL1+PLN1-DE1/(T(J)+273.)
           IF(DWLN.GE.87.0) DWLN = 87.0
           DW(J) = EXP(DWLN)
          ELSE
           PL1=PL2
```

```
      PLN1=PLN2
      DE1=DE2
      APL1 = APL2
      APLN1 = APLN2
      ADE1 = ADE2
      IF(J.LE.1) THEN
       DWLN = APL1 + APLN1-ADE1/(T(1)+273.)
       IF(DWLN.GE.87.0) DWLN = 87.0
       DW(1) = EXP(DWLN)
      ELSE
       DWLN=PL1+PLN1-DE1/(T(J)+273.)
       IF(DWLN.GE.87.0) DWLN = 87.0
       DW(J) = EXP(DWLN)
      END IF
     END IF
    END IF
   END DO
   IF (JJJJ.LT.2) THEN
    DO I=1,JINC
     SUM(I) = .5*DW(I)
    END DO
   ELSE
    DO I=1,JINC
     IF (SUM(I).LT.(1.0E38)) SUM(I)=SUM(I)+DW(I)
    END DO
   END IF
   IF (NXTRA.NE.0) THEN
    DO J=1,NXTRA
     IF (XTMP(J).LT.44.) THEN
      XDW(J) = 0.
     ELSE
      IF (XTMP(J).LT.50.) THEN
       APL1 = APPL1
       APLN1 = APPLN1
       ADE1 = ADDE1
      ELSE
       APL1 = APL2
       APLN1 = APLN2
       ADE1 = ADE2
      END IF
      IF (TP.EQ.999..AND.XTMP(4).GE.45.)
+ TP=TIME
      DWLN = APL1+APLN1-ADE1/(XTMP(J)+273.)
      IF(DWLN.GE.87.0) DWLN=87.0
      XDW(J) = EXP(DWLN)
     END IF
    END DO
    IF (JJJJ.LT.2) THEN
     DO J=1,NXTRA
      XSUM(J) = 0.5*XDW(J)
     END DO
    ELSE
```

```
                DO J=1,NXTRA
                 IF (XSUM(J).LT.1.0E38) XSUM(J)=XSUM(J)+XDW(J)
                END DO
               END IF
              END IF
              EMTIME = AINT(1000.*(TIME+.00001))/100.
              IF(TIME.LT.10..AND.AMOD(EMTIME,1.).EQ.0..OR.TIME.GE.10.
     + .AND.AMOD(EMTIME,10.).EQ.0.) THEN
               WRITE(4,420)TIME,T(1),T(2),T(3),T(4),T(5),T(6),T(7),
     + T( 8),T(9),T(10),T(11),T(12)
               PTS=PTS+1
              ENDIF
              IF (ITFLG.NE.0.AND.TIME.GE.ETIME.OR.JJJJ.EQ.M*100.OR.JJJJ
     + .EQ.1) CALL SUB12(TIME,T,XTIME,JINC,BLUD,CP,BK,NXTRA,XTMP,M,EM)
             END DO
             REWIND(4)
             CLOSE(4)
             DO I=1,JINC
              W(I) = (SUM(I)-.5*DW(I))*AK
             END DO
             IF (NXTRA.NE.0) THEN
              DO J=1,NXTRA
               XW(J) = (XSUM(J)-.5*XDW(J))*AK
              END DO
             END IF
C*******Select W(J) and D(J) near W(J) =1
470          NN = 3
             J=1
             DOWHILE(J.LE.JINC)
              JLT1 = J
              IF(W(J).GT.1.) THEN
               IF(J.EQ.JINC) THEN
                NN=2
                WRITE(3,440)(W(K),K=JLT1-1,JLT1+1)
                WRITE(7, 440)(W(K),K=JLT1-1,JLT1+1)
440    FORMAT(/(1X,'W=',E20.5))
                WRITE(3,450)(D(K),K=JLT1-1,JLT1+1)
                WRITE(7,450)(D(K),K=JLT1-1,JLT1+1)
450    FORMAT(/(1X,'D=',E20.5))
               END IF
               J=J+1
              ELSEIF(W(J).EQ.1.) THEN
               MN=1
               J=JINC+1
              ELSEIF(W(J).LT.1.) THEN
               IF (J.EQ.1) JLT1=2
               IF (J.EQ.JINC) JLT1=JINC-1
               WRITE(3,440)(W(K),K=JLT1-1,JLT1+1)
               WRITE(7,440)(W(K),K=JLT1-1,JLT1+1)
               WRITE(3,450)(D(K),K=JLT1-1,JLT1+1)
               WRITE(7,450)(D(K),K=JLT1-1,JLT1+1)
               IF (NXTRA0.NE.0.AND.JLT1.LE.2) THEN
```

```
                WRITE(*,460)
460     FORMAT(/,9X,'W=1 LIES ABOVE NODE 2.  INTERCOLLATING VALUES OF D'/
     + ,9X,'AND W COMPUTED FROM INTERPOLATED VALUES OF D AND',/,9X,
     + 'TEMPERATURE. ',/)
                WRITE(3,460)
                WRITE(7,460)
                WRITE(1)D(1)
                WRITE(2)W(1)
                DO J=1,NXTRA
                 WRITE(1)XTRALG(J)
                 WRITE(2)XW(J)
                END DO
                DO J=2,JINC
                 WRITE(1)D(J)
                 WRITE(2)W(J)
                END DO
                REWIND 1
                REWIND 2
                DO J=1,JINC
                 READ(1)D(J)
                 READ(2)W(J)
                END DO
                REWIND 1
                REWIND 2
                NXTRAO = 0
                GO TO 470
               END IF
               J=JINC+1
              END IF
             END DO
         IF(MN.EQ.0) THEN
          NXTRAO = NXTRA
          IF (W(JLT1+1).EQ.0..AND.NN.EQ.3) NN=2
          IF(W(JLT1-1).LT.1.0)THEN
            TD=0.0
            IERR=0
          ELSE
            CALL DEPTH(D(JLT1-1),W(JLT1-1),NN,TD,IERR)
C*******If Lagrangian interpolation didn't work, use linear interpolation
            IF(NN.EQ.3) THEN
              IF(W(JLT1-1).GE.1.0.AND.W(JLT1).LE.1.0.AND.(D(JLT1-1).
     +       GT.TD.OR.D(JLT1).LT.TD)) THEN
                NN=2
                CALL DEPTH(D(JLT1-1),W(JLT1-1),NN,TD,IERR)
              ELSEIF (W(JLT1).GE.1.0.AND.W(JLT1+1).LE.1.0.AND.
     +       (D(JLT1).GT.TD.OR.D(JLT1+1).LT.TD)) THEN
                JLT1=JLT1+1
                NN=2
                CALL DEPTH(D(JLT1-1),W(JLT1-1),NN,TD,IERR)
              ENDIF
            ENDIF
          ENDIF
```

```
         IF (IERR.NE.0) THEN
          WRITE(*,480)
          WRITE(3,480)
          WRITE(7,480)
480     FORMAT(9X,'ERROR IN SUBROUTINE "DEPTH". EXITING.'/)
          CALL ANOTHER(AGAIN)
         ENDIF
         IF (NN.EQ.2.AND.JLT1.EQ.JINC) THEN
          WRITE(3,490)MAXDIM
          WRITE(7,490)MAXDIM
490     FORMAT(/1X,'THE MODEL BLEW UP: DAMAGE > 1 AT NODE ',I2/)
          CALL SUB1020(W,JINC,D,TMPMAX,TD,TIME,TP)
         ELSE
          CALL SUB1020(W,JINC,D,TMPMAX,TD,TIME,TP)
         ENDIF
        ELSE
         TD=EXP(D(J))
         CALL SUB1020(W,JINC,D,TMPMAX,TD,TIME,TP)
        END IF
        CALL HARVARD(PROFILE,TFILE,SUMFILE,PTS)
       END IF
      ELSEIF(PROCED.EQ.1) THEN
       IF(AGAIN.EQ.0) THEN
        CALL SHOWVALUE(TEMPIO,DENS,FLUX,BL,AK,JINC,TEMPB,
     +  ABSORB,BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,
     +  BLOOD,APL1,APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
       ENDIF
      ENDIF
     END DO
     CLOSE(1)
     CLOSE(2)
     CLOSE(3)
     CLOSE(4)
     CLOSE(7)
     CALL COLORS
     DUMMY2=SETVIDEOMODE( $DEFAULTMODE )
     STOP
     END

     SUBROUTINE COLORS
        INCLUDE 'FGRAPH.FD'
        INTEGER*2 LOOP,LOOP1,DUMMY2
        REAL RND1,RND2
        DUMMY2=SETVIDEOMODE( $MRES256COLOR )
        DO LOOP1=1,10
        WRITE(*,10)
10     FORMAT(///,10X,'BURNSIM',///,15X,'BURNSIM',///,20X,'BURNSIM')
        DUMMY2=SETCOLOR(MOD( getcolor()+1, 16)) ! Set next color

         DO loop=1,3200
C*******Set a random pixel, normalized to be on the screen
          CALL RANDOM( RND1 )
```

```
          CALL RANDOM( RND2 )
          DUMMY2=SETPIXEL( INT2( RND1*320 ),INT2( RND2*200 ) )
         END DO
        END DO
        DUMMY2=SETVIDEOMODE( $MAXRESMODE )
        END

      SUBROUTINE WELCOME(PROFILE)
        CHARACTER PROFILE*8
        CALL CLEARSCREEN( $GCLEARSCREEN )
        WRITE(*,10)
10      FORMAT(//,9X,'WELCOME TO BURNSIM. TO BEGIN RUNNING THE PROGRAM,',
     + ' BURNSIM',/,9X,'FIRST NEEDS TO KNOW THE NAME OF THE FILE THAT',
     + ' YOU WANT TO',/,9X,'STORE THE OUTPUT DATA IN. THIS FILE WILL',
     + ' CONTAIN ALL OF THE',/,9X,'INPUT PARAMETERS AS WELL AS THE',
     + ' OUTPUT FOR EACH ITERATION THE',/,9X,'MODEL PERFORMS. THIS',
     + ' FILE CAN BE CALLED ANYTHING UP TO EIGHT',/,9X,'CHARACTERS',
     + ' LONG.',//,15X,'PLEASE ENTER A NAME FOR THE OUTPUT FILE: '$)
        READ(*,20)PROFILE
20      FORMAT(A8)
C*******Set up parameters for this run
        CALL CLEARSCREEN( $GCLEARSCREEN )
        WRITE(*,30)
30      FORMAT(///,9X,'NEXT BURNSIM WILL SHOW YOU THE PRESENT INPUT',
     + ' PARAMETERS.',/,9X,'UNDER THE LIST OF PARAMETERS YOU WILL SEE A'
     + ,' QUESTION ASKING',/,9X,'IF YOU WISH TO CONTINUE. IF YOU WANT',
     + ' TO EXIT THE PROGRAM AT ',/,9X,'THAT POINT, TYPE N. OTHERWISE',
     + ' TYPE Y.',///,9X,'TO CONTINUE ON TO THE LIST OF INPUT',
     + ' PARAMETERS TYPE A <CR>.')
        READ(*,*)
        END

      SUBROUTINE READDATA(TEMPIO,DENS,QO,BL,AK,BOIL,ABSORB,JINC,
     + TEMPB,ITIME,ETIME,PCWATR,BLOOD,CP,BK,PL2,PLN2,PL1,PLN1,DE2,
     + DE1,APL1,APLN1,APL2,APLN2,ADE1,ADE2,WATER)
        REAL ITIME
        DIMENSION CP(12,2),BK(12,2),WATER(12,2)
        OPEN(UNIT=1,FILE='REN12.DAT',FORM='FORMATTED',STATUS='OLD')
        READ(1,10)TEMPIO,DENS,QO,BL,AK,BOIL,ABSORB
10      FORMAT(7F10.5)
        READ(1,20)JINC,TEMPB,ITIME,ETIME,PCWATR,BLOOD
20      FORMAT(1I10,5F10.5)
        READ(1,30)(CP(J,2),J=1,JINC)
30      FORMAT(6F10.5)
        READ(1,30)(BK(J,2),J=1,JINC)
        READ(1,30)PL2,PLN2,PL1,PLN1,DE2,DE1
        READ(1,30)APL1,APLN1,APL2,APLN2,ADE1,ADE2
        READ(1,30,END=40)(WATER(I,2),I=1,JINC)
40      CLOSE(1)
        CALL CLEARSCREEN( $GCLEARSCREEN )
        END
```

```
      SUBROUTINE SHOWVALUE(TEMPIO,DENS,FLUX,BL,AK,JINC,TEMPB,
     + ABSORB,BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,
     + NXTRA,BLOOD,APL1,APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
        REAL ITIME
        DIMENSION FLUX(600),XTRA(8)
        CALL CLEARSCREEN( $GCLEARSCREEN )
        IF(K.NE.1) THEN
         WRITE (*,10)
10     FORMAT(///,30X,'SKIN DIFFUSION DATA'/,30X,'INPUT PARAMETER LIST')
         WRITE(*,20)TEMPIO,DENS,FLUX(1),BL,AK,JINC,TEMPB,ABSORB,BOIL
20     FORMAT(/,4X,'TEMPIO = ',F10.5,6X,'DENS = ',F10.5,7X,'Q1 = ',
     + F10.5,/,4X,'BL = ',F10.5,10X,'AK = ',F10.5,9X,'JINC = ',I2,/,4X,
     + 'TEMPB = ',F10.5,7X,'ABSORB = ',F10.5,5X,'BOIL = ',F10.5,/)
         WRITE (*,30)PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,BLOOD
30     FORMAT(4X,'PL1 = ',F10.5,9X,'PLN1 = ',F10.5,7X,'DE1 = ',F10.1,/,
     + 4X,'PL2 = ',F10.5,9X,'PLN2 = ',F10.5,7X,'DE2 = ',F10.1,/,4X,
     + 'ETIME = ',F10.5,7X,'ITIME = ',F10.5,6X,'NXTRA = ',I2,/,4X,
     + 'BLOOD = ',F10.5,/)
         WRITE(*,40)APL1,APLN1,ADE1,APL2,APLN2,ADE2
40     FORMAT(4X,'APL1 = ',F10.5,8X,'APLN1 = ',F10.5,6X,'ADE1 = ',F10.1,
     + /,4X,'APL2 = ',F10.5,8X,'APLN2 = 'F10.5,6X,'ADE2 = ',F10.1,/)
         IF (NXTRA.GT.0) WRITE(*,50) (XTRA(I),I=1,NXTRA)
50     FORMAT(5X,'THE EXTRA NODES ARE: ',8F6.1)
        ELSE
         WRITE(3,10)
         WRITE(7,10)
         WRITE(3,20)TEMPIO,DENS,FLUX(1),BL,AK,JINC,TEMPB,ABSORB,BOIL
         WRITE(7,20)TEMPIO,DENS,FLUX(1),BL,AK,JINC,TEMPB,ABSORB,BOIL
         WRITE (3,30)PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,BLOOD
         WRITE (7,30)PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,BLOOD
         WRITE(3,40)APL1,APLN1,ADE1,APL2,APLN2,ADE2
         WRITE(7,40)APL1,APLN1,ADE1,APL2,APLN2,ADE2
         IF (NXTRA.GT.0) WRITE(3,50) (XTRA(I),I=1,NXTRA)
         IF (NXTRA.GT.0) WRITE(7,50) (XTRA(I),I=1,NXTRA)
         K=0
        ENDIF
        END

      SUBROUTINE PROCEED(RESP,PROCED,AGAIN)
        CHARACTER RESP*1
        INTEGER PROCED,AGAIN
        WRITE(*,10)
10     FORMAT(//,15X,'DO YOU WISH TO CONTINUE? TYPE Y OR N '$)
        READ(*,20)RESP
20     FORMAT(A1)
        IF (RESP.EQ.'Y'.OR.RESP.EQ.'y') THEN
         PROCED=0
        ELSE
         PROCED=1
         CALL ANOTHER(AGAIN)
        ENDIF
        END
```

```
      SUBROUTINE ANOTHER(AGAIN)
        CHARACTER RESP*1
        INTEGER AGAIN
        WRITE(*,10)
10    FORMAT(//,15X,'DO YOU WANT TO DO ANOTHER RUN?  TYPE Y OR N '$)
        READ(*,20)RESP
20    FORMAT(A1)
        IF(RESP.EQ.'Y'.OR.RESP.EQ.'y') THEN
         AGAIN=0
        ELSE
         AGAIN=1
        END IF
        END

      SUBROUTINE DESCRIPT(DSCRPT,SUMFILE,TFILE)
        CHARACTER SUMFILE*8,TFILE*8
        DIMENSION DSCRPT(20)
        WRITE(*,10)
10    FORMAT(///,9X,'ENTER THE MODEL NAME OR DESCRIPTION (UP TO 80',
     + /,9X,'CHARACTERS).  THIS INFORMATION WILL BE USED',/,9X,
     + 'AS A TITLE ON THE SUMMARY PAGE. '$)
        READ(*,20)DSCRPT
20    FORMAT(20A4)
        WRITE(3,30)DSCRPT
30    FORMAT(//,10X,'MODEL NAME OR DESCRIPTION: ',20A4)
        CALL CLEARSCREEN( $GCLEARSCREEN )
        WRITE(*,40)
40    FORMAT(///,9X,'NOW ENTER THE SUMMARY FILENAME (UP TO 8',
     + /,9X,'CHARACTERS).  THIS FILE WILL CONTAIN A',/,9X,'SUMMARY'
     + ' OF THE SIMULATION. '$)
        READ(*,50)SUMFILE
50    FORMAT(A8)
        OPEN(UNIT=7,FILE=SUMFILE,FORM='FORMATTED',STATUS='UNKNOWN')
        WRITE(7,30)DSCRPT
        CALL CLEARSCREEN( $GCLEARSCREEN )
        WRITE(*,60)
60    FORMAT(///,9X,'NOW ENTER THE TEMPERATURE FILE (UP TO 8',
     + ' CHARACTERS).',/,9X,'THIS FILE WILL CONTAIN A LIST OF THE',
     + ' TEMPERATURES',/,9X,'AT THE VARIOUS NODES DURING THE SIMULATION'
     + '. '$)
        READ(*,70)TFILE
70    FORMAT(A8)
        OPEN(UNIT=4,FILE=TFILE,FORM='FORMATTED',STATUS='UNKNOWN')
        END

      SUBROUTINE SUB12(TIME,T,XTIME,JINC,BLUD,CP,BK,NXTRA,XTMP,M,EM)
        DIMENSION T(12),XTIME(12),CP(12,2),BK(12,2),XTMP(8)
        WRITE(3,10)TIME
        WRITE(*,10)TIME,(T(I),XTIME(I),I=1,JINC)
10    FORMAT(/,45X,5HTIME=,F10.6:,T4,'T= ',6X,'XTIME='/('',2G12.4))
        WRITE(*,20)BLUD
20    FORMAT(1X,'BLUD =',F6.5)
```

```
         WRITE(3,30)(XTIME(I),I=1,JINC)
30      FORMAT(2X,'XTIME=',F10.5)
         WRITE(3,40)T(1),CP(1,1),BK(1,1)
40      FORMAT(2X,'T=',G16.5:,2X,'CP=',G16.5,2X,'BK=',G16.5)
         IF (NXTRA.NE.0) THEN
          DO J=1,NXTRA
           WRITE(3,40)XTMP(J)
          END DO
         END IF
         WRITE(3,40)(T(J),CP(J,1),BK(J,1),J=2,JINC)
         M=M+1
         EM = M
         END

      SUBROUTINE DEPTH(X,Y,N,TD,IERR)
C*******Inverse interpolation on two or three points to determine
C        threshold depth (predicted burn depth) using either Y or LOG(Y)
         DIMENSION X(1),Y(1),Z(3)
         IERR = 0
         IF (N.LT.2) IERR=-1
         IF(IERR.NE.-1) THEN
          DO 100 I=1,N
100       Z(I) = Y(I)
          Z0 = 1.
          IF (Z(1).NE.0..AND.Z(2).NE.0.) THEN     !USE LOGARITHMS?
           IF (N.EQ.3.AND.Z(3).EQ.0.) N=2
           Z0 = 0.          !USE LOGARITHMS
           DO 120 I=1,N
120         Z(I) = ALOG(Z(I))
          END IF
140       H0 = Z(2)-Z(1)
          IF (H0.EQ.0.) IERR=-1
          IF (N.NE.2.AND.IERR.NE.-1) THEN
           H1 = Z(3)-Z(2)
           IF (H1.EQ.0.) IERR=-1
           IF(IERR.NE.-1) H2 = Z(3)-Z(1)
           IF (H2.EQ.0.) IERR=-1
           IF(IERR.NE.-1) DZ3 = Z0-Z(3)
          END IF
          IF(IERR.NE.-1) THEN
160        DZ2 = Z0-Z(2)
           DZ1 = Z0-Z(1)
           IF (N.NE.2) THEN
            TD = DZ1*DZ2*X(3)/(H1*H2)-DZ1*X(2)*DZ3/(H0*H1)+X(1)*DZ2*DZ3
     + /(H0*H2)
           ELSEIF(N.EQ.2) THEN
180         TD = (DZ1*X(2)-X(1)*DZ2)/H0
           END IF
200        TD = EXP(TD)
          END IF
         END IF
         END
```

```
      SUBROUTINE SUB1020(W,JINC,D,TMPMAX,TD,TIME,TP)
         DIMENSION W(12),D(12)
         WRITE(3,10)(W(I),I=1,JINC)
10    FORMAT(/(1X,'W=',E20.5))
         WRITE(7,20)(W(I),EXP(D(I)),I=1,JINC)
20    FORMAT(/(1X,'W =',E20.5,5X,'AT DEPTH (IN MICRONS)=',G20.6))
         WRITE(3,30)TMPMAX
         WRITE(7,30)TMPMAX
         WRITE(*,30)TMPMAX
30    FORMAT(/,1X,'MAXIMUM TEMPERATURE = ',F8.3)
         WRITE(*,40)TD
         WRITE(3,40)TD
         WRITE(7,40)TD
40    FORMAT(/,1X,'THRESHOLD DEPTH = ',G20.4)
         WRITE(3,50)TIME
         WRITE(7,50)TIME
         WRITE(*,50)TIME
50    FORMAT(/,1X,'FINAL TIME = ',F7.2)
         IF(TP.NE.999.) THEN
          WRITE(3,60)TP
          WRITE(7,60)TP
          WRITE(*,60)TP
60    FORMAT(/,1X,'TIME TO PAIN IS ',F7.2,' SECONDS.')
         END IF
         END

      SUBROUTINE HARVARD(PROFILE,TFILE,SUMFILE,PTS)
         CHARACTER PROFILE*8,SUMFILE*8,TFILE*8,HGPLOT*1,HG*12
         INTEGER PTS
         WRITE(*,10)
10    FORMAT(///,9X,'TYPE A <CR> TO CONTINUE.')
         READ(*,*)
         CALL CLEARSCREEN( $GCLEARSCREEN )
         WRITE(*,20)
20    FORMAT(///,9X,'DO YOU WANT TO PLOT THE TEMPERATURES VS. TIME',/,
     + 9X,'TIME IN HARVARD GRAPHICS? TYPE Y/N '$)
         READ(*,30) HGPLOT
30    FORMAT(A1)
         IF(HGPLOT .EQ. 'Y' .OR. HGPLOT .EQ. 'y') THEN
          CALL PLOTHG(PTS,TFILE,HG)
         ENDIF
         CALL CLEARSCREEN( $GCLEARSCREEN )
         WRITE(*,40)PROFILE,TFILE
40    FORMAT(//,9X,'THE MODEL OUTPUT IS FOUND IN FILE: ',A10,/,9X,
     + 'USE "PRINT" OR "TYPE" AFTER YOU EXIT THE PROGRAM TO SEE IT.',
     + //,9X,'THE TEMPERATURES AT EACH NODE ARE IN FILE: ',A10,/,9X,
     + 'USE "PRINT" OR "TYPE" AFTER YOU EXIT THE PROGRAM TO SEE IT.')
         IF(HGPLOT .EQ. 'Y' .OR. HGPLOT .EQ. 'y') THEN
          WRITE(*,50)HG
50    FORMAT(//,9X,'THE TEMPERATURES FOR THE HARVARD GRAPHICS PLOT',
     + ' ARE IN FILE: ',/,9X,A12,'. USE "PRINT" OR "TYPE" AFTER YOU',
     + ' EXIT THE PROGRAM',/,9X,'TO SEE IT.')
```

```
      ENDIF
      WRITE(*,60)SUMFILE
60    FORMAT(//,9X,'THE SUMMARY PRINTOUT IS IN FILE: ',A10,/,9X,'USE',
     + ' "PRINT" OR "TYPE" AFTER YOU EXIT THE PROGRAM TO SEE IT.',///,
     + 12X,'TYPE A <CR> TO CONTINUE.')
      READ(*,*)
      CALL CLEARSCREEN( $GCLEARSCREEN )
      END

   SUBROUTINE PLOTHG(PTS,TPFILE,HG)
      REAL TIME(800),T1(800),T2(800),T3(800),T4(800),T5(800),
     + T6(800),T7(800),T8(800),T9(800),T10(800),T11(800),T12(800)
      INTEGER PTS
      CHARACTER HG*12,TPFILE*8
      OPEN(UNIT=4,FILE=TPFILE,FORM='FORMATTED',STATUS='UNKNOWN')
      DO I=1,PTS
       READ(4,40) TIME(I),T1(I),T2(I),T3(I),T4(I),T5(I)
     + ,T6(I),T7(I),T8(I),T9(I),T10(I),T11(I),T12(I)
40    FORMAT(13(F9.5,2X))
      END DO
      WRITE(*,10)TPFILE
      CLOSE(4)
10    FORMAT(/,9X,'THE TEMPERATURE DATA IS STORED IN FILE: ',A8)
      WRITE(*,20)
20    FORMAT(/,9X,'ENTER THE FILE TO STORE HARVARD GRAPHICS ',/,
     + 9X,'TEMPERATURES USING UP TO 12 CHARACTERS',/,9X,'INCLUDING'
     + ' THE ENDING .DAT ',$)
      READ(*,30) HG
30    FORMAT(A12)
      IF(PTS.LE.60) THEN
       OPEN(UNIT=5,FILE=HG,FORM='FORMATTED',STATUS='UNKNOWN')
       DO J=1,PTS
        WRITE(5,60) TIME(J),T1(J),T2(J),T3(J),T4(J),T5(J),
     + T6(J),T7(J),T8(J),T9(J),T10(J),T11(J),T12(J)
60    FORMAT(13(F9.5,2X))
       END DO
       CLOSE(5)
      ELSE
       INTERVAL=INT(PTS/60)
       OPEN(UNIT=5,FILE=HG,FORM='FORMATTED',STATUS='UNKNOWN')
       DO J=1,PTS,INTERVAL
        WRITE(5,80) TIME(J),T1(J),T2(J),T3(J),T4(J),T5(J),
     + T6(J),T7(J),T8(J),T9(J),T10(J),T11(J),T12(J)
80    FORMAT(13(F9.5,2X))
       END DO
       CLOSE(5)
      END IF
      END
```

APPENDIX C

REN12.DAT

This next file contains the initial values of the variables and constants required by BURNSIM. The file is REN12.DAT.

```
32.5,1.,3.54,0.22,0.01,100.15,0.613
12,4.5,80.,3.02,0.137,0.001
.5139,.8513,.8678,.8681,.8561,.8349,.8086
.7802,.7537,.7326,.7209,.7209
.00059604,.0012236,.0012541,.0012547,.0012322,.0011931,.0011439
.0010912,.0010419,.0010028,.0009810,.0008
2.24,239.47,1.46,147.37,80000.,50000.
.78,285.52,.60,117.43,93534.9,39109.8
.137,.72596,.75574,.75638,.73439,.69632,.64869
.598,.55081,.51364,.49298,.3
```

See the users manual for definitions of these abbreviations (eg. TEMPIO).

<u>ROW 1</u>

TEMPIO = 32.5
DENS = 1.
QO = 3.54
BL = 0.22
AK = 0.01
BOIL = 100.15
ASORB = 0.613

<u>ROW 2</u>

JINC = 12
TEMPB = 4.5
ITIME = 80.
ETIME = 3.02
PCWATER = 0.137
BLOOD = 0.001

<u>ROW 3</u>

Cp(1) = .5139
Cp(2) = .8513
Cp(3) = .8678
Cp(4) = .8561
Cp(5) = .8561
Cp(6) = .8349
Cp(7) = .8086

<u>ROW 4</u>

Cp(8) = .7802
Cp(9) = .7537
Cp(10) = .7326
Cp(11) = .7209
Cp(12) = .7209

<u>ROW 5</u>

BK(1) = .00059604
BK(2) = .0012236
BK(3) = .0012541
BK(4) = .0012547
BK(5) = .0012322
BK(6) = .0011931
BK(7) = .0011439

<u>ROW 6</u>

BK(8) = .0010912
BK(9) = .0010419
BK(10) = .0010028
BK(11) = .0009810
BK(12) = .0008

<u>ROW 7</u>

PL2 = 2.24
PLN2 = 239.47
PL1 = 1.46
PLN1 = 147.37
DE2 = 80000.
DE1 = 50000.

<u>ROW 8</u>

APL1 = .78
APLN1 = 285.52
APL2 = .60
APLN2 = 117.43
ADE1 = 93534.9
ADE2 = 39109.8

<u>ROW 9</u>

WATER(1) = .137
WATER(2) = .72596
WATER(3) = .75574
WATER(4) = .75638
WATER(5) = .73439
WATER(6) = .69632
WATER(7) = .64869

<u>ROW 10</u>

WATER(8) = .598
WATER(9) = .55081
WATER(10) = .51364
WATER(11) = .49298
WATER(12) = .3

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